

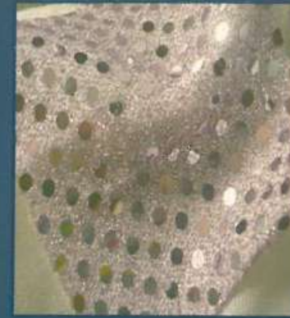

Proceedings

INNOVATION

The New Paradigm for the Textile and Fashion Industry

Edited by
Sanjay Gupta

INNOVATION
THE NEW PARADIGM FOR THE TEXTILE & FASHION INDUSTRY

Proceedings

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Innovations In Wet Processing

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Innovations in wet processing are a continuous process driven by various factors that may include energy conservation, economy, environmental considerations or developments in associated technologies. Currently the innovations are being driven by the customer who has become knowledgeable and most concerned with his health, hygiene, comfort and fashion. Health considerations represent both the ecology and the direct contact of the user with the product. In this respect textiles as an alternate medicine are also being promoted. Hygiene deals with the odour control and the comfort is concerned with the maintenance of body temperature. Fashion driven technologies may even reduce the life of the product but still they are considered important be it worn-out look or casual look. It is also giving impetus to garment processing. Developments in Information Technology, Biotechnology and Nanotechnology has given rise to many innovative products and processes that are adding special characteristics and value to the final end product.

The chemical processors have been ever innovating to meet the various challenges that may be due to energy crisis or environmental consideration or product development requirements. There have been different types of driving forces for innovations from time to time. Development in technology has always being one of them. Some of the present driving forces for innovation are: health, hygiene, comfort and fashion. These are all customer-driven.

HEALTH AS A DIRECT AND INDIRECT DRIVING FORCE

We are fast progressing towards knowledge based global society where there is substantial awareness created among the user of textile products. Data on all types of chemicals and processes is easily accessible though worldwide web. The customer may be living in a different region or environment and would like his textile material to be produced in such a manner that it does not affect his health directly or indirectly. The first serious indication of this paradigm change came with the famous 'German Ban' where more than 140 dyes and a dozen of chemicals were subjected to serious scrutiny for their effect on the health of user and restriction imposed on their use in the chemical processing of textiles. This has led to search for alternate chemicals and processes that are human-friendly. The health concerns in the production and use of textiles have being expressed in various direct and indirect ways. Some of there have resulted in the,

(a) Development of novel more environmentally friendly processes;
(b) Use of non-toxic dyes and chemicals;
(c) Use of health giving finishes; and
(d) Enhanced interest in UV protection finishes.

DEVELOPMENT OF NOVEL MORE ENVIRONMENTALLY FRIENDLY PROCESSES

Preparatory Processes

Any process that consumes less energy or has lower water consumption is considered environmentally friendly hence healthy process. This has given birth to a host of combined preparatory processes wherein the chemical producers have joined hand with the machinery manufacturers to produces such systems, i.e., Roco-Yet of Ramisch Kleinewefers, Ben-Bleach of Investa, Flexinip of Küsters and Convi-Tex C of Babcock. In all these processes a desizing, scouring and bleaching formulation based on novel nonionic surfactants and hydrogen peroxide has been suggested that has to be applied in such a manner that there is very good penetration of the chemicals on the hydrophobic gray fabric, that is followed by steaming and thorough washing. Thereby a considerable saving in energy, water and labour has been achieved with high productivity.

Dyeing

For the dyeing processes lower material to liquor ratio dyeing machines are being developed the latest from Devrekha claiming to dye at a material to liquor ration of 1:1. Continuous microprocessor control dyeing ranges have been developed for maximum utilization of energy and water.

Environmental considerations have given impetus to the development of reactive dyes that can be dyed with minimum amount or preferably no salt. Be it multi-functional reactive dyes or cationic reactive dyes the objectives are to reduce TDS in the spent dye liquor. Alternate electrolytes such as sodium citrate have been tried but have been found to be expensive. Modification of cellulosic substrates so as to make them more receptive towards reactive dyes has been a serious topic of research in recent times. Specialty chemical manufacturers are busy testing the efficacy of their cationic products to enhance the affinity of reactive dyes towards treated cellulosic substrates without substantially adversely affecting the light fastness of the resultant dyed products. The new slogan is towards "salt-free" dyeing.

Researchers from the Innsbruck Institute for Textile Chemistry and Physics, Austria, have developed an Electro-Chemical Dyeing process with Vat dyes, ECDVAT process. They worked with industrial partners from Germany DyStar Textilfarben GmbH and Thies Textilmaschinenbau to produce technology for electrochemical reduction in textile dyeing.

The first technical installation worldwide to colour cotton textile electronically has been built at the Getzner Textil AG in Bludenz, Austria. The new method replaces chemicals, which are not reusable, with electrons. "Important advantages include better process control and less water contamination during the dyeing," says Professor Thomas Bechtold from the university in Innsbruck. This process has received the SDC Innovation in Colour Award 2004.

Use of ultrasonic in the coloration of selected textile substrates generates cavitation (Hot bubbles) thereby it offers several benefits such as, (a) energy saving by dyeing at low temperature with shorter dyeing time, and (b) reduced consumption of auxiliary chemicals resulting into lower pollution. Commercial model of the dyeing machines fitted with Ultrasonic Power Supply system (USP) are being produced by Morko Company of Korea. Dyeing machines fitted with USP not only dye at lower temperature and in shorter time but also are very effective in washing of the dyed fabrics.

Research on the development of non-aqueous dyeing systems has been going on for almost last 40 years. Initially perchloroethylene was considered and some commercial machines were developed but the process did not receive commercial success. Later on Prof. Schollmeyer developed a process of dyeing from supercritical carbon dioxide as an environmentally friendly coloration process. However, the process has yet to be commercialized. Recently dyeing from reverse micelle system has been suggested. Reverse micelle systems have been widely studied to extract proteins in liquid-liquid extraction system. In a reverse micelle system a surfactant such as Astowet OT (Sodium bis -2-ethyalhexylsulphosuccinate) is dispersed in a non-polar solvent such as iso-octane to form a reverse micelle as shown in Fig. 1. In the reverse micelle the hydrophilic end of the surfactant form the inner core that is capable of holding water. The dye gets dissolved in the water held by the micelle and gets transferred to the fibre during dyeing when the micelle comes in contact with the fibre. Such systems consume very little water.

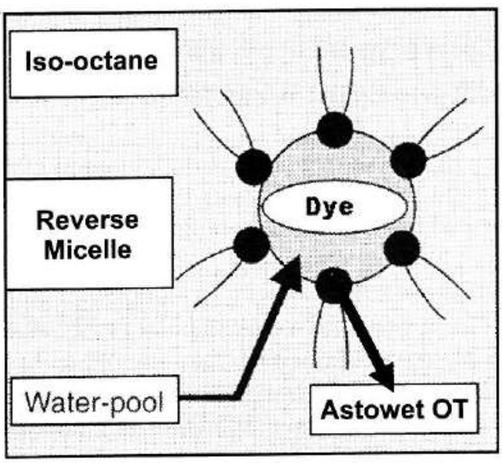

Fig. 1 Reverse micelle dyeing system

Printing

Pigment printing dominates the current printing processes, since it is not fibre specific. Moreover, the prints can be fixed with dry heat and don't require after wash hence it has found large-scale acceptance. In the conventional process oil-in-water thickening systems are used that have been found to be non-human friendly, not only during printing but also due to residual oil in the printed fabrics. A system to recover kerosene from the printed fabrics has been developed by BTRA and has some commercial support. However, more attention has been given to the alternate thickening systems mostly based on synthetic polymeric systems where high molecular weight cross-linked aqueous dispersible polymeric compounds have been developed and found substantial market support even though the results have been slightly inferior to those obtained with the conventional oil-in-water system.

Impetus to transfer printing has been given by the growing concern about the large-scale pollution created by the conventional printing processes. The development in the IT industry has also been responsible for its revival. In the current transfer printing process the design may be loaded on the computer form digital camera or through scanner. The output may be taken on an ink-jet printer on a transfer paper using specially selected colorants. The paper may be directly used for printing of the fabric or garment. Thereby making the process totally water or pollution-free.

Finishing

Finishing of textile fabrics involves drying of large amount of water from the padded material. Removal of water by mechanical methods works out to be economical as compared to the thermal methods. Hence many devices have been developed wherein the water is substantially mechanically removed such as,

(a) Roberto Roll, a roll with groves on the surface so the water can be removed by the combined action of squeezing and by capillary action of the

(b) Vacuum slit, where in the padded wet fabric is passed over a slit connected to high vacuum that sucks the loosely held water there by substantially rescuing the water content of the fabric to be dried after the application of the finish

In order to avoid the use of chemicals that may be injurious to the skin or the health of the wearer there has been shift from chemical to mechanical finish. With the result many types of surface-effect finishes have been developed that includes: brushing, raising, sueding, emerising, embossing and peach finish. These mechanical finishes are considered more human friendly (healthy) as compared to the chemical finishes that not only involve chemicals abut also require large amount of energy for fixation.

There is substantial interest in the application of finishes in the ionized form created by cold plasma. The process does not produce wastewater or chemical effluents, so the method is economical and reduces the environmental impact caused by the chemical textile industry. Hydrophilic as well as hydrophobic and oleophobic modifications on textiles can be carried out by changing the treatment parameters. The hydrophobic and oleophobic properties of the textile surfaces are based on a thin coating by hydrofluorcarbons and fluorocarbons on the fibres by the plasma process, creating low surface energies.

Europlasma has designed and developed a full-scale production unit for plasma treatment of textiles. The plasma coating works on the nano-scale, permeating the surface of the material so that the coating covers the individual fibres, rather than forming a barrier "sheet" over the top. This means that the material retains its original bulk properties - a textile will keep the same drape qualities and will not stiffen or irritate

Non-toxic dyes and chemicals

A recent Swedish study entitled "Chemicals in textiles" showed that hazardous chemicals occur in the following functional groups: biocides, fire-retardants, dyes (azo and dispersion dyes), carriers, softeners, formaldehydes, etc. Such substances have a function in the final product or are residual adjuvant chemicals used in the manufacturing process (e.g. carriers and nonyl phenol ethoxylates).

All chemicals and dyes cause some pollution during manufacture, use and disposal. One of the major problems is assessing the eco-friendliness of a given chemical or dye. Many approaches involving 'Cradle to Grave' approach have been suggested. BASF have developed an Eco-efficiency Analysis System. Eco-efficiency analysis considers the economic and life cycle environmental effects of a product or process, giving these equal weightage. The six major elements of the environmental assessment include (a) primary energy use, (b) raw materials utilization, (c) emissions to all media, (d) toxicity, (e) safety risk, and (f) land use. Any chemical or dye can be analyzed by this method. BASF has already analyzed 150 textile dyes and auxiliary chemicals for their eco-efficiency. Eco-efficiency analysis has been verified by the German technical inspection organization TŰV.

TŰV has also instituted a certification scheme called TOXPROOF. The products that pass the tests can be labelled with the TOXPROOF label. The label is developed to prove that according to present day knowledge, no health risks are to be feared from the product.

Emphasis on eco-friendliness has given impetus to the use of biotechnology in the production and processing of textile dyes, auxiliary chemicals.

For instance pigments are produced by a wide variety of fungi. Currently, the pigments produced by microorganisms and used commercially are: riboflavin, β-carotene and phycocianin (a blue pigment used in food and cosmetics).

Among the textile dyes CI Disperse Blue 7 and CI Acid Green 28 have been produced from the anthaquinones produced by a strain of *Curvularia lunata* fungus. Bioindigo has also been produced by the action of *E. coli* on the bacterial tryptophan. Bio-surfactants have also been produced by the controlled bacterial strains.

There has been some revival of natural dyes also, in spite of their having limited colour gamut and fastness characteristics. Innovative way of using these dyes has been via the fibre-dyeing route. Wherein cotton fibres are dyes and blended to increase the colour gamut as well as overcome the problem of uneven coloration.

Use of enzymes in the processing of textiles has been steadily increasing as demonstrated in Fig. 2.

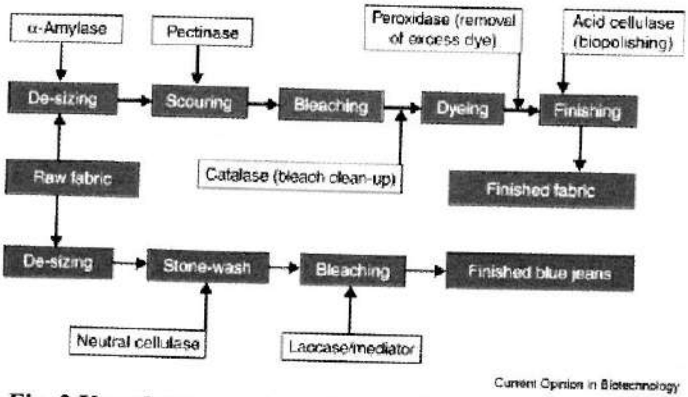

Fig. 2 Use of enzymes in various textile chemical processes

Enzymes act as biocatalysts to accelerate the process and are required in small quantities. The residual enzyme being easily biodegradable does not add much to the BOD and COD of the effluent. Further the catalytic action of enzymes does not require severe process condition of high temperature or pH. The action of enzymes is specific hence no by-products are formed and the efficiencies of the reaction are considerably increased.

Use of health giving finishes

During Christmas of 2002 Osaka-based manufacturer Teijin introduced Amino Jeans and sold 2 million pairs in 24 hours. Amino Jeans are treated with arginine, an amino acid said to keep the skin youthful. Fatty acid in the new fabric also moisturizes the skin, smell nice, and fight bacteria. The health benefits should survive at least two years of regular laundering, claims the company.

Fuji Spinning Co., Ltd. has a line of underwear, laced with seaweed and caffeine, that it says burns fat when the ingredients are absorbed into the skin and interact with sweat and body oils. The extract activate fat-dissolving enzymes, claims the company, and continue to be absorbed by the body even after the underclothes have been washed many times.

The company also makes Vitamin C-spiked undershirts and pajamas that are said to remove skin blemishes and improve circulation. Other fashion leaders hope to build up business by helping people lose weight with help from their sense of smell.

Shiseido's Inicio Body Creator incorporates grapefruit and pepper scents that are said to stimulate the nervous system so that the body burns fat.

Ohara Paragium Chemical Co., Ltd. is actively involved in the development of functional finishing agents in pursuit of cosmetic, health-oriented and relaxation effects. The natural skincare and healthcare finishing agents aim at improved skincare and healthcare and are divided largely into the following two types.

1. A new type of softening agent that can produce unconventional, less-sleek but full, elegant silky hand (Amino-acid-based new softening agents).

2. Finishing agents that take aim at producing moisture retaining, slimming or anti-ageing (anti-oxidation) effects. Health-oriented, skincare finishing agents such as capsaicin, raspberry, rice germ oil (ferulic acid,-oryzanol), Vitamin E.

There are many other companies such as Cognis that have come out with such products having microencapsulated fragrances for aromatherapy and stress releasing oils.

UV protection finishes

UV radiation accounts for only six percent of the total wavelengths range of sunlight. Although these rays provide the desired suntan on the skin, over exposure to the ultraviolet (UV) rays of the sun is associated with skin cancer, cataracts, and other disease, according to the United Nations Environment Program. They estimated "over two million non-melanoma skin cancers and 200,000 malignant melanomas occur globally each year," and expect this to rise as stratospheric ozone decreases. This has given impetus to the development of UV protection finishes. Two types of finishes have been developed namely inorganic and organic that can be used to enhance the UV protection provided by the textiles.

Inorganic UV filters are produced from micro-fine particles of titanium dioxide or zinc oxide that reflect the incident UV light like tiny mirrors. Since these pigments are white, at higher concentrations they may have an undesired whitening effect on the fabric. Reducing the size of the pigment particles to about 200 nanometers, which makes them appear transparent, prevents this.

The organic UV finishes are based on cinnamic acid derivatives, benzophenones, triazines, benzotriazoles, p-aminobenzoic acid esters and methoxy dibenzoylmethane derivatives and are being sold under various trade names. These are all UV absorbers and some have substantively for the substrates on which they are applied.

HYGIENE

Hygiene has acquired importance in recent years. Odour has become an important factor. Unpleasant odours can arise from the acquisition of a variety of compounds produced in bodily fluids, including urine, menstrual fluid and perspiration.

Considerable R&D is being carried out to develop odour-absorbing finishes. Cyclodextrin has emerged as the prominent molecule around which various finishes are being developed. Various other approaches include treatment with N-halamines. These compounds absorb chlorine that prevents microorganism growth and thus prevent generation of foul odour. In yet another approach carboxyl groups are grafted on cotton fabrics, these groups react with ammonia and triethyal amine given out during perspiration. Subsequently they are washed out and regenerate the carboxyl groups. Microencapsulated fragrances are also being used to mask the odour.

Microorganism growth is another factor that has resulted in the development of anti-microbial finishes. Microorganisms not only give rise to various kinds of diseases but also are responsible for odour generation. Triclosan is the most popular anti-microbial agent. The Sanatized™ finish of Clariant is based on Triclosan and has over 80% of the market share. It is based on 5-chloro-2- (2,4-dichloro phenoxy) phenol. Being a chlorophenol has been subject of controversy. Other antimicrobial agents in use are ÆGIS Microbe Shield™ based on 3-trimethoxysilyal - propyaloctadecyl ammonium chloride, AgION™ is silver deposited on zeolite and Purista™ textile products are having poly (hexamethylene biguanide) hydrochloride (PHMB) as anti-microbe. Attachment of chitosan on to fibres by cross-linking has been suggested as natural antimicrobial finish. Neem based natural antimicrobial finishes are also under development.

COMFORT

Comfort and protection have acquired significance and have become integral part of the textile garment. Initially comfort was considered synonym to feel of a fabric. Kawabata and FAST systems were developed to assess feel. Sweat also makes the garment uncomfortable. Those fabrics that could transmit the moisture effectively were considered comfortable.

Maintenance of body temperature close to 31°C is considered comfortable and many finishes are being developed to maintain the body temperature to the desired level. One of the options to regulate the body temperature that is being currently exploited is the use of phase change materials (PCMs). Ciba Specialties has recently introduced Encapsulence PC140 finish based on phase change material for use on textile fabrics. Phase change materials absorb, store, or release heat as the cycle between solid and liquid form. During physical activity, the wearer's excessive body heat increases and is absorbed by the encapsulated phase change materials. As activity ceases, the body cools and the microcapsules return the stored heat back to the wearer that maintaining the body temperature to desirable comfortable temperature.

Many such finishes that not only maintain the body temperature but also the moisture are being developed to cater to the growing need of having comfort an integral part of the finished garment.

FASHION AS A DRIVING FORCE

The awareness of the environmental damage caused by textile production has provoked a different response from the textile industry than from the fashion industry. The textile industry has had to address pollution caused by the 'processing' of textiles, in most cases as a direct response to pressures from environmental legislation. The fashion industry, on the other hand, has focused on the 'product' itself. 'Green' textile and fashion products have appeared in designer collections, exclusive fashion stores. What has resulted in these two different approaches is 'an apparent division between the producers of textiles on the one hand, and the clothing industry on the other.'

By 1992, the natural 'eco-look' was mainstream fashion. Designers continued to take their inspiration and colour palette from natural surroundings. Unbleached and organic fabrics such as cotton, linen and silk, in natural, earthy tones became popular. Natural fibres and dyes are widely believed to be more environmentally favourable as they come from a renewable resource and are biodegradable.

Designers in the future could play a leading role in integrating environmental criteria into a product's overall marketing and communication strategy. However, if designers are to change our patterns of consumption, they need information on the environmental impact of the processes and materials they use. The design process is presently divorced from the constraints imposed on manufacturers by the regulators and several designers have commented they had little or no knowledge of environmental implications of their design decisions and fabric specifications.

However, there are many wet processes that have found acceptance because they are able to create a kind of 'look' that is in vogue. One of the interesting examples of this is the treatment of the indigo dyed denim fabric with enzymes - the so-called bio-wash. It randomly strips the dye from the treated garment creating a product that has found huge customer acceptance. Evolution of this process is purely fashion driven. The fall out is sand wash, stone wash, snow wash. laser engraving and now the Vagobondo look produced from pigment dyed washed garments. Special machines have been developed to give treatment to produce the desired kind of effect.

Acceptance of the casual look by the customer has opened up a new field of garment processing and the development of required equipment and machines for garment processing. In some of the machines a vapour phase treatment is given to full garment. This requires a new set of low temperature curable specialty chemicals and the catalytic systems. A variety of shape and memory polymers are being developed for this purpose.

TECHNOLOGY - A CONSTANT DRIVING FORCE

Three technologies that are driving innovation in the wet processing are:

1. Biotechnology technology,
2. Information technology, and
3. Nanotechnology

Biotechnology

Biotechnology is an integration of three disciples that is biochemistry, microbiology and chemical engineering. It is said that biotechnology is the harbinger of third industrial revolution (first two being steam power and microprocessor).Most industrial applications of biotechnology are still based upon fermentation processes catalysed by bacteria and enzymes. However some technologies where genetic engineering is being used to harness the power of DNA molecule are being developed. DNA probes have been the direct outcome of these researches. DNA can be designed to stick very specifically to other species of DNA and thereby, to help identify target species. Impetus to the use of DNA probes has come from importers to identify the products and overcome the labeling frauds such as to distinguish between wool and cashmere (Pashmina).

Use of enzymes in wet processing has already been mentioned above. Other areas where biotechnology is aiding the wet processing is in the treatment of effluents to remove colour and heavy metals, additive in aftercare products (detergents), production of dyes, surfactants, biosensors and genetic modification as well as production of biopolymers.

The application of biotechnology represents the future of the industry that has pollution problems caused by the use of classical procedures. It seems to be a good solution to clean production technology. However, in the absence of the understanding of all the reactions involved in biochemical processes it is still considered as a 'black art'.

Information technology

Information technology has speeded up all operation of the industry. In the wet processing industry apart form having microprocessor controlled production machines that are integrated with the master computer that can provide solutions to the on going processes any where in the world, it is finding use in colour measurement and electronic communication as well is in developing new printing technologies.

There have been significant improvements in colour difference measurement equations and reduction of subjectivity in colour difference assessment. The results of the lab dip sample can be communicated electronically to the buyers and the approval obtained in much shorted time. Similarly the colour difference can be expresses in easily understandable terms and pre-shipment approvals obtained to cut down on delivery time. Use of fuzzy logic in colour measurement is being pursued actively.

Nanotechnology

Nanotechnology is currently the most high-tech buzz world. This term was originally used by Eric Drexler for the production of biological nanomachines however now the term nanotechnology covers a whole range of very different developments, ranging from nanostructuring of surfaces right up to nanoparticulate systems. BASF has identified six areas in which nanotechnology will have a market share of 220 billion euro by 2010, these are:

Nanoparticles, Nanocomposites, Surface treatment, Systems to analyse nano- structures, Lateral nanostructures, and Ultra thin layers.

Nanostructured materials that are important for textile processing are: Nanoparticles, Colloids, Formulations, Ultra thin layers, Nanostructures, Composites, Polymers, Surfaces, and Catalysts.

Many companies have come out with finishes based on nanotechnology that are being promoted as superior finishes as compared to the conventional ones. Some of the companies are:

1. Nano-Tex: Founded in 1998, has developed finishes for garments that include: *Resists Spills* Spill resistant fabric enhancement for many types of fibres that repels a range of liquids, *Coolest Comfort* Quick-absorbing fabric enhancement providing superior wicking properties to synthetic fabrics, which pulls perspiration away from the body and dries it quickly to keep the body cool and comfortable. *Cotton Touch* Naturally soft fabric enhancement designed to make synthetic fabric look and feel like cotton.

2. Schoeller Textil AG: The NanoSphere® finishing technology is based on the self-cleaning principle and is nearly a perfect copy of nature. Splashes and annoying stains don't have a chance: ketchup, honey, coffee, red wine, oil and grease, as well as water of course, simply run of the nano-surface-even after numerous washes.

3. Texcote-processing technology results in a layer of protective coating on the surface of the fabrics and around the fibres. Water and stain repellency of the fabric is enhanced many- fold after Texcote-processing treatment. Other benefits of Texcote-processing treatment include air permeability, easy of care and environmental-friendliness.

4. Anson Nanotechnology Group Co. Ltd. (ANG) is a Hong Kong-based company pioneering in the research and development of nanotechnology. ANG's research and development are categorized into four major products groups that include Textile and Non-Woven Fabrics. Textile includes cotton yarn, cotton fabric, socks and other types of textile products; Non-Woven Fabrics include baby diaper, household cleaning materials, female hygiene products and filtering materials.

5. NYACOL® NANO TECHNOLOGIES is the leader in colloidal dispersions and nano-particle technology. The products include flame-retardants for textiles and plastics, UV absorbers and acid scavengers, anti-block and abrasion resistance additives for films and colloidal dispersions for catalysts.

Nanotechnology is still in its infantile stage and has to be market - tested. Most of the nanotechnology products are being applied to create innovative surfaces that have self-cleaning and non-stick properties. One may observe a large-scale innovation activity in this field.

CONCLUSION

There has been a paradigm shift in the concepts, technology and terminology of wet processing. With the globalization, ease of communication and information explosion the technology gap is decreasing.

The customer has become more knowledgeable and demanding. Health seems to be of prime concern. Hence all the future developments will have to go though eco-audit before it is considered for implementation. Future textiles will be smarter and multifunctional incorporating multiple technologies.

The textile processors will have to upgrade their knowledge and skills and keep abreast with developments in associated fields to meeting the most discerning customers.

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Fibre Innovations In Technical Textiles Applications

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The ever increasing applications of textile material in technical textile sectors such as protective clothing, medical and health care products, automotive components, building material, geotextiles, agriculture, sport and leisurewear, filter media, environmental protection, etc. has been the driving force behind innovations in fibre technology. The paper discusses fibre requirement for diverse range of technical applications and relates the fibre properties with end-use requirements and highlight some of the developments in modified, high technology and specialty fibres.

The driving force for important fibre developments, especially in past two decades has been the ever increasing applications for fibrous material in non-conventional sectors such as protective clothing, medical and health care products, automotive components, building material, geotextiles, agricultue, sport and leisurewear, filter media, environmental protection etc. These applications put strong demands on good performance properties such as strength, modulus, durability and dimensional stability and on functions such as flame retardancy, hydrophilicity, hydrophobicity, biocompatibility etc.

Textile Terms and Definitions, TI publication, defines technical textiles as "textile materials and products manufactured primarily for their technical performance and functional properties rather than their aesthetic or decorative characteristics". Technical textiles are generally recognised to be one of the most dynamic and promising area for the future of the textiles industry. Advances in polymers, fibres, yarns, chemical technology and fabric/web forming technologies and a large number of fibre innovations during last 35 years have spearheaded the material development for technical textiles.

Applications Of Technical Textiles

Technical textiles are literally all around us. On the floor, the carpet will have backing layers and underlays made of polypropylene or polyester. Nonwoven filters are used in vacuum cleaner and in the kitchen exhaust hood or in air-conditioning units. Furniture now uses elastic webbings instead of springs as well as flame retardant fibre fillings and lining fabrics in place of the dangerous foams which produce toxic fumes. The header tapes on the curtains, the pull strings on the blinds and the sealing strips on double glazed windows are all technical textiles. Elsewhere in the home and workplace, nonwovens are to be found as cleaning cloths, specially impregnated wipes and as carriers for the new generation of fabric conditioners.

The average car contains 13-14 kg of textiles, not only in the obvious areas - the carpets, upholstery, body liners and seat belts - but also as flexible reinforcements in the tyres, water hoses, brake pipes and timing belts. Parts of the bodywork and even the suspension system are increasingly likely to be made of glass fibre reinforced composites. Heat resistant and sound absorbing textiles may be used to insulate various parts of the vehicle. Oil and fuel filters will be keeping the car operating smoothly; there is even an increasing trend to filter the air that enters the passenger compartment using nonwoven media. And finally, a vital component that must meet the most stringent technical requirements but will, hopefully, never be used is the airbag concealed within the steering wheel or passenger dashboard.

Under the highway on which the car drives is likely to be some geotextile, helping to maintain a firm base for the foundations of the road or preventing cracking of the surface layer of tarmac. Geotextiles will also be found in the embankments of roads, railways and rivers, preventing slippage on steep slopes and perhaps helping new vegetation to get a hold. The drains beside the road may be lined with fabric, allowing free flow of water but less susceptible in the long term to breakage and blockage than conventional land drains.

Sports may be played on pitches, courts and tracks covered with artificial turf made from polypropylene yarn, using textile nets and textile-covered or reinforced balls. Golf clubs, skis, tennis rackets and fishing rods are all made from fibre-reinforced composites. Many sports use specialised clothing to provide protection from injury, cold or overheating. Skiwear in particular tends to be a showcase for the latest and most sophisticated technical fabrics because of the high prices that can be obtained at the top end of this market. Specialized heat insulating and retaining fabrics have been developed, as well as novelty effect materials that change colour with temperature.

The whole field of medicine and healthcare is an important user of technical textiles. Surgical gowns and drapes are increasingly being required to offer protection against the smallest quantities of body fluids that might contain AIDS or hepatitis. Diseased arteries and veins can be by-passed with lengths of finely knitted tubing while damaged ligaments in the knee can be replaced with strong textile supports. After an operation, fine sutures, traditionally made of silk but increasingly likely to use more modern biologically compatible polymers will be used to sew up the wound. The list of other applications for textiles in medicine, ranging from hollow fibres for dialysis to surgical cotton wool for general cleaning and absorbency applications is a long one.

Even everyday clothing contains many technical textiles as essential components. Interlinings help to preserve the shape and firmness of the fabrics to which they are bonded by finely dispersed thermoplastic polymer coatings. Waistbands prevent curl and distortion, wadding and felts give added bulk and shape to garments. Shoes also contain many textile components as linings and insoles; these are increasingly likely to be made from one of the new generation of long-life, bacteria-killing fibres which help to keep feet fresh, especially during strenuous sports activity.

Reinforcements for fragile optical fibre cables, ultra-light weight fishing nets and climbing ropes, bullet proof vests, covers for hardback books; from the exotic to the ordinary, technical textiles are everywhere and becoming more widespread all the time.

There have been many attempts to create a useful classification of technical textile end-use sectors. The most recent is that put forward (Table 1) by Messe Frankfurt, the organisers of the Techtextil trade show in Frankfurt and Techtextil Asia in Osaka.

Table 1: End-use Sectors for Technical Textiles (TECHTEXIL)

• Agriculture	• Clothing	• Home	• Packaging
• Automotive	• Environment	• Industry	• Protection
• Building	• Geotextiles	• Medical	• Sports

Tables 2 and 3 show the consumption of different technical textiles both in terms of weight and value respectively and estimate of their growth over next five years.

Table 2: Forecast World Technical Textiles Consumption, 1995-2010, Vol. (000 tons)

Application Area	Years				Compound Annual Growth Rate %		
	1995	2000	2005	2010	95-00	00-05	05-10
Agrotech	1,173	1,381	1,615	1,958	3.3%	3.2%	3.9%
Buildtech	1,261	1,648	2,033	2,591	5.5%	4.3%	5.0%
Clothtech	1,072	1,238	1,413	1,656	2.9%	2.7%	3.2%
Geotech	196	255	319	413	5.4%	4.6%	5.3%
Hometech	1,864	2,186	2,499	2,853	3.2%	2.7%	2.7%
Indutech	1,846	2,205	2,624	3,257	3.6%	3.5%	4.4%
Medtech	1,228	1,543	1,928	2,380	4.7%	4.6%	4.3%
Mobiltech	2,117	2,479	2,828	3,338	3.2%	2.7%	3.4%
Packtech	2,189	2,552	2,990	3,606	3.1%	3.2%	3.8%
Protech	184	238	279	340	5.3%	3.3%	4.0%
Sporttech	841	989	1,153	1,382	3.3%	3.1%	3.7%
Totals*	**13,971**	**16,714**	**19,683**	**23,774**	**3.7%**	**3.3%**	**3.8%**
Of which Oekotech*	*161*	*214*	*287*	*400*	*5.9%*	*6.0%*	*6.9%*

Source: David Rigby Associates/ Techtextil **Already counted in several categories above*

Table 3: World Technical Textile Consumption by Application area (Value US $ mn)

Application Area	Year				CAGR %		
	1995	2000	2005	2010	95-00	00-05	05-10
Agrotech	4587	5541	6568	8079	3.9	3.5	4.2
Buildtech	4449	5872	7296	9325	5.7	4.4	5.0
Clothtech	5202	6070	7014	8306	3.1	2.9	3.4
Geotech	565	740	927	1203	5.5	4.6	5.3
Hometech	5866	6750	7622	8778	2.8	2.5	2.9
Indutech	10990	13405	16687	21528	4.1	4.5	5.2
Medtech	4391	5391	6670	8238	4.2	4.3	4.3
Mobiltech	23596	25629	26861	29282	1.7	0.9	1.7
Packtech	3658	4393	5329	6630	3.7	3.9	4.5
Protech	4692	5193	5873	6857	2.1	2.5	3.1
Sporttech	12902	13897	16052	19062	1.5	2.9	3.5
Total*	80898	92881	106899	127287	2.8	2.9	3.6
*Of which Oekotech	616	800	1039	1389	5.4	5.4	6.0

Source: David Rigby Associates/ Techtextil **Already counted in several categories above*

Technical textiles are likely to grow by 3.3% per annum by weight and by 2.9% by value between years 2000 and 2005 and by 3.8% per annum by weight and by 3.6% by value between years 2005 and 2010.

Fig. 1 shows product-wise consumption of technical textiles. It is evident that major uses of technical textile products are in the form of fabrics. Fig. 2 gives a break-up of different fabric types that are being used as technical textiles.

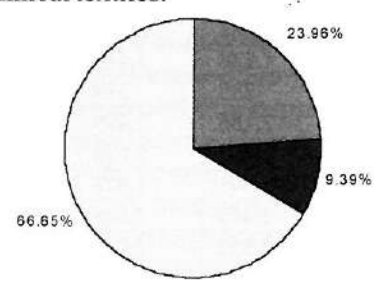

Fig. 1: product-wise consumption of technical textile (Source: DRA)

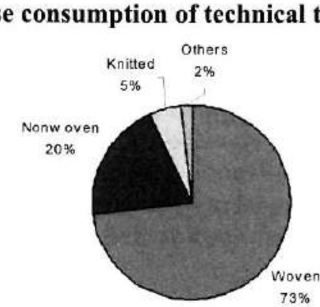

Fig. 2: Global end-use of technical textile fabric (Source: DRA)

FIBRE USAGE IN TECHNICAL TEXTILES

Technical textiles market is a large and growing market which fibre producers should increasingly target. The technical textiles at present account for more than 20% of all fibres consumed. The fibre usage in technical textiles both in terms of % of total fibres used and the amount of fibre consumed in Kg per capita in the three main industrial areas of the world is shown in Table 4.

Table 4: Fibre usage in technical textiles in selected areas

Area	'Textile' fibres only	Textile fibre, PP tape and monofilaments	Textile fibre, PP tape, monofilaments and glass
W Europe	20% (2.8kg)	27% (4.3kg)	33% (5.6kg)
USA	16% (4.0kg)	21% (5.2kg)	27% (7.9kg)
Japan	30% (4.9kg)	32% (5.3kg)	39% (6.2kg)

Virtually all kinds of fibres (both natural and man-made) are used in technical textiles. Many types of fibres are used, from regular, cheap polyester in large quantities to very expensive and very special purpose fibres in small quantities. Although most technical textiles require performance characteristics related to the application, they do not usually need to be made from special fibres. But the 'technology' of technical textiles does not always reside purely in the products themselves or the way in which they are made. It also includes the know-how for their application to a wide range of end-uses in the fields of aerospace, industry, medicine and healthcare, defence and security services, safety, leisure, transport, construction, agriculture and fishing. Technical textiles often substitute for existing materials and techniques but also open up some completely new possibilities and new approaches to solving problems.

Fibres are consumed in technical textile applications in many forms. Fig. 3 shows the estimated pattern of consumption of fibres in various forms for manufacture of technical textiles.

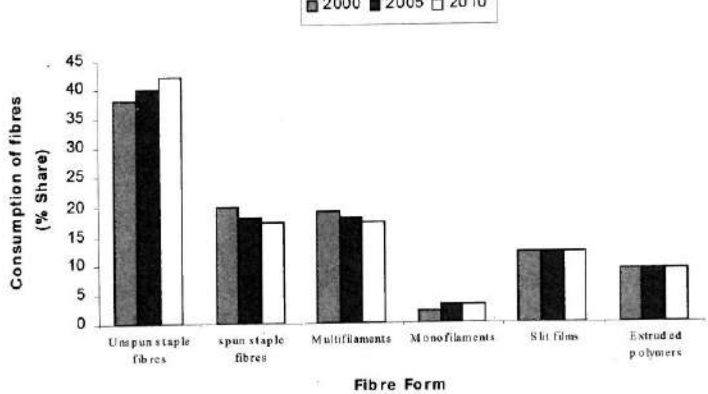

Fig.3: Consumption of fibres in various forms for manufacture of technical textiles (source: DRA)

Fibres used in technical textiles can be divided into two main classes, namely:

(a) commodity fibres, both conventional and high tenacity;
(b) high-technology or specialty fibres.

Majority of technical end-uses of textiles are based on commodity fibres (Table 5). A high degree of engineering ingenuity is, however, often devoted to the design of the item constructed from such fibres.

High technology or specialty fibres are those which very often are made involving novel materials and sophisticated manufacturing techniques. These fibres are normally characterized for their certain performance enhancing properties. High technology fibres normally add value to the finished products.

Table 5: Fibre types used in technical textiles

Fibre Type	Estimated % by Weight of Total Technical Textile Usage
1. Regular conventional fibres (eg cotton, polyester)	69
2. High tenacity fibres (eg HT polyester)	28
3. High performance (eg carbon, aramid)	2
4. Special performance (eg anti-bacterial, colour change)	1
TOTAL	100%

Figure 4 depicts relative consumption volumes of various fibres in technical textile. It is evident that polyester and polypropylene are the dominant players of the technical textile market.

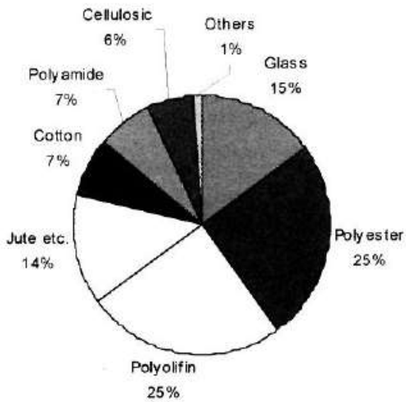

Fig. 4: Fibre consumption in technical textiles (source: DRA)

The introduction of high performance fibres (Fig, 5) in technical textiles has allowed us to enter a new era of materials revolution. These fibres are used for special requirements demanded by certain types of technical textiles applications. Such technical requirements can be high temperature protection, high impact and dynamic energy absorption capacity, high cut-through resistance, etc. In other words, high-technology or specialty fibres are normally chosen for their particular suitability to an end-use such as protective clothing for ballistic body armour, for high-risk jobs and sports, lightweight textile-reinforced structural components for aircraft, high-performance ropes for marine applications, structural panels (reinforced with fibres) for building construction and so on. Aramids (Kevlar, Nomex, Twaron etc.), glass, carbon, polyethylene, polyphenylene sulphide, polyetheretherketone (PEEK), polytetrafluroethylene (PTFE) etc. are some of the popular high-technology fibres frequently used for technical textiles.

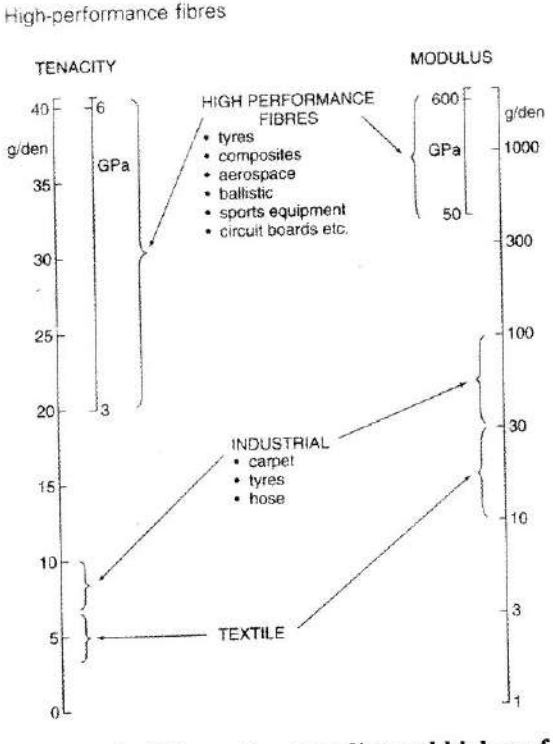

Fig 5: Strength and stiffness of commodity and high performance fibres

Tailor-made special properties are very often the features of high-technology fibres. For example, today fibres can be engineered into hollow structures that are capable of providing the varying degree of porosity and strength needed in medical applications such as synthetic blood vessels, controlled drug release etc.; in chemical/water industry applications such as purification, filtration etc.; in civil engineering and many other applications. Table 6 highlights some specific attributes of some high technology fibres. These are successfully exploited on a wide variety of technical textile products to enhance performance.

	Attributes	Example Fibres	Example Application Areas
1	Strength and stiffness	p-aramid, glass, carbon, polyethylene, inorganics and aromatic copolymers	Load-bearing and non-load-bearing structural components for aircraft, protective clothing for high-risk jobs and sports, civil engineering and marine applications
2	Thermal stability and resistance	m-aramid, PTFE and inorganics	Protective clothing for fire brigades, chemical industry etc.
3	Thermal stability and mechanical performance at elevated temperature	Carbon, ceramics etc.	Space Shuttle components, combustion chambers and chamber linings of boilers and heaters etc.
4	Chemical stability	PTFE	Reaction chamber linings, protective clothing linings etc.
5	Other special properties	Glass	Optical fibres for telecommunications etc.

Useful Fibre Properties For Technical Textiles

The long-term durability, dimensional stability, etc. of technical textiles are functions of many fibre properties. For example, thermal and thermomechanical responses of fibres describe the usefulness of the long-term utilisation of a fibre in a technical textile particularly to be used in a hostile environment such as hot gas or liquid filtration, welders' suits or even textiles used in tyres. The knowledge of various fibre properties thus allows the manufacturers of technical textiles to have a logical estimation of the suitability and subsequently the durability of the materials used in a particular environment so as to minimise the risks of unwanted failure due to the interaction of stress-deformation-temperature and degradative chemical reactions.

Specific fibre properties are required for the specific technical applications. Main properties required in many of the technical applications can be grouped as follows:

1. mechanical properties (strength, extensibility, modulus/stiffness, elastic recovery etc.);
2. thermal and thermomechanical properties (melting temperature, high temperature mechanical properties etc.);
3. chemical characteristics (resistance to various inorganic and organic chemicals etc.);
4. electrical properties (static build-up, dielectric behaviour, insulating nature etc.);
5. ageing behaviours (oxidative, thermal ageing etc.);
6. surface properties (adhesion, moisture transport behaviour etc.);
7. optical properties;
8. other special properties.

Commodity Fibres for Technical Textile Application

Most technical textiles are made from everyday polymers and materials such as polyester, polypropylene, polyamide (nylon), viscose, cotton, jute and even glass (Fig. 4). The properties and structure of the fibres, yarns and fabrics made from these materials are often significantly modified compared with those used for conventional clothing and household textiles.

Innovations have been achieved with regular polymers like polyester, nylon, viscose, etc. by modifying their physical shape and dimensions in fibre form, or by imparting special additional functional properties by chemical treatment. High strength and modulus fibres have been made using same polymers by modifying the spinning process. Table 7 shows some of the methods used for making innovative fibre structures using commodity polymers.

Table 7: Examples of methods for obtaining sophisticated fibrous structures

Method	Examples
Modification of existing polymers	Hydrophilic polyester and acrylics Antistatic nylon and polyester
Modification in the fibre-forming stage	High shrinkable fibres Hollow fibres; Ultrafine fibres
Modification of fibre and yarn assemblies	Combines filament yarn (nylon, polyester) Tightly woven fabrics, double-knits
Modification by surface finish	Water and oil-repellence; Antistatic Perspiration property absorption
Lamination technique	Bonding of fabrics to polymer film
Coating technique	Coating of fabrics with micro-porous or hydrophilic polymer layer

Improved fibre spinning techniques in melt spinning, wet spinning, dry spinning and new techniques such as gel spinning, bicomponent spinning, microfibre spinning, have made it possible to produce fibres with characteristics more suitable for use in technical textiles. It is now possible to produce man-made fibres with highly sophisticated non-circular cross sections, blends of filaments in a yarn having "differential shrinkage", splitting of bicomponent filaments, surface treatments to produce required morphology and topography.

The bicomponent fibre technology is mainly used to produce microfibres, binder fibres, self-crimpable fibres, electro-conductive fibres and heterofil yarns. The three main types of bicomponent fibres are core-sheath, side-by-side and islands-on-sea (Fig. 6).

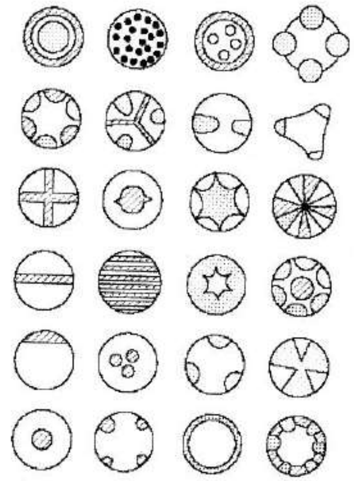

Fig. 6: Conjugate fibre cross sections

Figure 7 below shows a photograph of a bicomponent islands-on-sea fibre type. Using this technology, microfibres or ultra-fine fibres have been developed successfully.

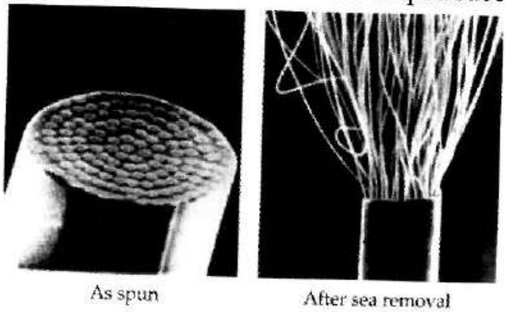

Fig. 7: Bicomponent islands-on-sea fibre

The dimensions are further decreasing with the advent of nano-technology. Electrospun nanofibres are being developed to produce special nonwovens for various technical applications.

The fibre cross section has been modified to various shapes to obtain specific properties such as lustre, thermal insulation, wicking, etc. One such example is shown in Fig. 8 is the 4DG deep grooved fibre. The fibre is having large surface per unit volume and as a result, is very efficient in wicking and in thermal insulation as well as filtration.

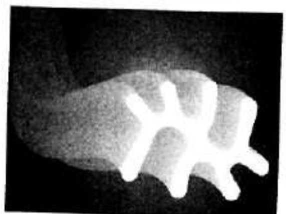

Fig. 8: The cross section of 4DG fibres

With the development of new spinning technology and the phase-change-materials, it has been possible to develop fibres with stimuli-responsive materials microencapsulated within the system. This has opened up a new area of research with smart fibres and created many new applications. Chemical modification of regular commodity fibres such as viscose, polyester, etc. to impart properties like flame retardancy has also paved the way for the extensive use of these modified fibres in technical applications.

New spinning processes and slight modification of polymer systems have enabled fibre producers to go for much higher speed of production of fibres having improved mechanical properties. High tenacity polyesters, polypropylene, etc. play a very significant role in applications such as ropes, nets, fishing twines, etc. Improvement in viscose process has resulted in Lyocell fibres with greater water absorbance and higher strength. These fibres are widely being used in making medical nonwoven products and wipes.

SPECIALTY & HIGH PERFORMANCE FIBRES FOR TECHNICAL TEXTILE APPLICATION

Conventional fibre types, both man-made and natural, still account for over 95% of all organic fibre technical textiles in use (i.e. excluding glass, mineral and metal fibres). Many of them have been modified and tailored to highly specific end-uses by adjustment of their tenacity, length, fineness, surface profile, finish and even by their combination into hybrid and bicomponent products. However, it is the emergence of the so-called high performance fibres since the early 1980s that has provided some of the most significant and dramatic impulses to the evolution of technical textiles.

A relatively small (albeit important and growing) proportion of technical textiles, perhaps 2-3% by volume, uses the so-called high-tech fibres; aramids such as Kevlar, Twaron, Nomex, carbon fibre and high molecular weight polyethylene (Dyneema, Spectra). Both the highly temperature resistant *meta-aramids* (widely used in protective clothing and similar applications) and the high strength and modulus *para-aramids* (used in a host of applications ranging from bullet proof vests to reinforcement of tyres, hoses, friction materials, ropes and advanced composites) are now widely used.The aramid fibres, while not huge in overall terms (representing less than 0.5% of total world technical fibre and yarn usage in volume terms but closer to 3-4% in value), the aramids represent a particularly important milestone in the development of the technical textiles industry.

Carbon fibres are used not only in aerospace markets but also of high technology sporting goods and industrial applications such as wind generator turbine blades and reinforced fuel tanks. As new manufacturing methods and greater economies of scale start to bring prices down, the feasibility of even larger scale applications such as the reinforcement of buildings and structures in earthquake zones becomes more attractive.

The introduction of other high performance fibres proliferated, particularly during the late 1980s, and in the wake of the aramids. These included a range of heat and flameproof materials suitable for protective clothing and similar applications (such as phenolic fibres and PBI, polybenzimidazole), ultra-strong high modulus polyethylene (HMPE) for ballistic protection and rope manufacture, and chemically stable polymers such as polytetrafluoroethylene (PTFE), polyphenylene sulphide (PPS) and polyethyletherketone (PEEK) for use in filtration and other chemically aggressive environments.

Specialty fibres are being developed for specific technical applications such as in medical textiles, protective clothing, etc. Alginate fibres, chitosan fibres, chlorofibre, electro-conductive polymeric fibre, artificial spider silk fibres are some of these.

Individually, none of these other fibres has yet achieved volume sales anywhere near those of the aramids (or even carbon fibres). Indeed, the output of some specialty fibres can still be measured in tens of tonnes per year rather than hundreds or thousands.

Inorganic Fibres for Technical Textiles

Glass has, for many years, been one of the most underrated technical fibre. Used for many years as a cheap insulating material as well as reinforcement for relatively low performance plastics (fibre glass) and roofing materials, glass is increasingly being recognized as a sophisticated engineering material with excellent fire and heat-resistant properties. It is now widely used in a variety of higher performance composite applications, including sealing materials and rubber reinforcement, as well as filtration, protective clothing and packaging; The potential adoption, of high volume glass-reinforced composite manufacturing techniques by the automotive industry as a replacement for metal body parts and components, as well as by manufacturing industry in general for all sorts of industrial and domestic equipment, promises major new markets.

Various higher performance ceramic fibres have been developed but are restricted to relatively specialized applications by their high cost and limited mechanical properties.

Concluding Remarks

The diverse applications of textile materials for technical purposes have opened up a new era of development in fibre science and technology. Existing fibres are being modified and new fibres are being developed to meet specific and stringent requirements of the technical textile applications. The critical role played by the technical textile products in most of the cases, and the undoubted advantage of their use has enabled a market of high value products. This allows the manufacturers to go for high value raw materials. In an industry where innovation has become the only means of survival, almost all the major players are engaged in research and development regarding raw materials and their applications. Development of other disciplines such as electronics, biotechnology, nanotechnology, etc. gives further boost and new possibilities for the development of new fibres.

Innovations in fibres for technical applications are taking place in two directions. One is by modifying the existing polymers and spinning technology to develop modified polymers with improved chemical and physical properties. Fibres are coming up with improved flame retardancy, smart properties and in a multitude of cross sections and ever decreasing dimensions.

Another direction of development is to use new polymers or materials for making fibres. Biopolymers, liquid crystals, electrically conducting polymers, etc. are being converted into fibre form to suit specific applications.

However, the ability of many of these fibres to be efficiently processed in existing textile machinery during yarn or fabric formation will largely determine their suitability and commercial success. Otherwise, new processing technology has to be developed to convert some of these fibres into the final technical textile form.

Many academic and industrial research centres are engaged in developing new fibres for new applications. News of such innovative developments is becoming a regular feature. A closer interaction between the fibre scientists, machine manufacturers, textile technologists and marketing people can lead to a more stable and steady growth of the technical textile industry. Undoubtedly, innovations in fibre science and technology will play a key role in this.

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Innovation In Wool Textiles

NATHAN LY

Australian wool has a leading position in the global supply of wool used in apparel. Australia accounts for around 48 per cent of the world production of wool used in apparel and 67 per cent of world Merino wool production in 2003. Australia also leads the international trade in finer Merino wool accounting for over 90 per cent of global production of Merino wool of 19.5 micron and finer.

Global retail demand for wool products, and for apparel use in particular, has been under intense economic and competitive pressure over the last decade. Wool in total has lost nearly 20% of its world volume consumption over the period 1993-2002 and 22% in the apparel sector.

Global demand for quality wool apparel has been challenged by low consumer purchasing confidence and fashion interest in some key retail markets such as Western Europe and Japan. The consumer trend favouring cheaper and more casual clothing has also tended to favour textiles man-made fibres and cotton in the mass retail sectors.

In contrast, to the declines experienced in Western Europe and Japan, where economic conditions have generally been difficult in the past decade, there has been a rising trend in apparel wool consumption in the USA up to the economic downturn in 2001 and in China up to 2001 on the back of stronger economic growth in the past decade. There has also been a strong recovery in wool consumption in South Korea since the downturn caused by the financial and economic crisis in that country in 1998

This growth in the USA, China and South Korea has been driven in large part by the strong economic conditions experienced in all these countries for much of the past decade.

Woolmark 2005, an extensive survey of four key markets (USA, Europe, developed and developing Asia), examined consumer purchasing, lifestyles, retail change and competitor fibre inventions looking forward to 2005. This survey, plus reports and projections since, show clear messages being sent by consumers, retailers and designers to woolgrowers, pipeline businesses and for wool R&D decision-making.

Key Apparel Purchase Drivers are practical demands by younger and older consumers for:

- Value for money genuine product differences for price or a cheaper product;
- Casual looks relaxed, less structured but not cheap or uniform fabrics;
- Comfort looser fit, lightweight, soft handle, breathability and stretch;
- Clothes that travel well wrinkle resist, durable;

- Convenience total easy care;
- Versatility multi-occasions, seasons, individuality; and
- Especially for young people, Lifestyle brands, 'branding' as global trend, and movement to 'Fast and Disposable Fashion' 'Cheap is Chic'.

Surveys of younger adults globally also confirm issues to be addressed by wool R&D. They have high regard for wool quality, softness and breathability but 50% see wool as difficult to care for and 42% think wool is itchy. Younger consumers and retailers link wool to formal wear and classic knitwear products for older people.

Australian Wool Innovation has developed a portfolio of Marketing Platforms and R&D Programs that reflect key drivers for wool innovation over the next five years and beyond. They are designed to provide a balance of market-driven and technology-push approaches for achieving R&D outcomes that will meet the market demand. Marketing Platforms represent market-driven approach to ensure that a continuing stream of fabric and product innovations, particularly for apparel, are delivered to defend existing wool markets and to build new and more diverse markets for wool. R&D Programs are the technology-push to position wool at the frontiers of fibre and textile research and can lead to the major breakthroughs that pave the way for new wool platform technologies.

R&D PROGRAMS:

Four R&D programs have been established to drive innovation in wool products and processes for the wool industry worldwide.

New Markets for Australian Merino Wool

Currently wool has lost much of the women's and children's wear market and needs to gain more access to the growing sports and active wear sector. This program will develop new marketing concepts and innovative wool garments that will be attractive to retailers. It involves working with designers, garment makers and retailers to build new product ranges.

Non apparel market opportunities also exist for fine Merino wool. These include areas such as industrial filtration and medical bandages. A clear need to respond to these competitive challenges through the development and commercialisation of novel wool products in new markets is the key driver of this program.

The goal of this program is to create new markets for Australian Merino wool in the apparel and non-apparel markets through the following activities:

Market analysis

During the first six months of this program planning will be undertaken to review opportunities for new uses of wool in market sectors such as women's knitwear, women's tailoring, children's wear, sport/active/surf-wear, technical textiles, industrial textiles, and uniforms. Specific opportunities in the domestic Chinese and USA markets will also be researched. This may include consumer and retail surveys of selected market sectors.

Product development with designers and garment

In conjunction with The Woolmark Company, and other suppliers, key designers and garment makers who use wool, or may do so, will be approached to become involved in collaborative design projects aimed at innovative use of wool in apparel.

Development and commercialisation of novel products

Develop technologies to enhance product appeal including the handle of wool fabrics, at the same time develop new apparel products employing the non-woven and fibre knit processes.

Non apparel products

A review will be conducted of all potential non-apparel uses of fibres of all types. This review will consider alternative uses for wool that might be suitable for AWI to evaluate. Market analysis and evaluation will be conducted to invest in developments where the returns are most attractive.

IMPROVED APPEARANCE RETENTION

Appearance retention of wool woven and knitted garments in wear is a key aspect of their quality. Appearance problems have been well documented in consumer and industry surveys and are recognised by processors. The higher price of wool garments (over synthetic) creates an expectation of good performance. Garments that pill, wrinkle, fade or change colour are the subject of complaints by consumers.

Many of the causes of these problems are known, especially pilling and wrinkle recovery. However, current technologies offer only partial solutions and are expensive or inconvenient. This results in a wide range of quality in wool garments. Moreover, the limitations inherent in these technical options restrict the range of wool products that can be produced.

Total Easycare technology is particularly applicable to the USA knitwear market and a special initiative is underway with The Woolmark Company to exploit this opportunity.

The goal of this program is to develop and facilitate adoption of innovative technologies that correct deficiencies in the appearance retention of wool apparel products (fading, pilling and cockling in knitwear and wrinkling in woven products).

The following research areas will be addressed:

- Bright colours
- Pilling of knitwear
- Loop distortion in knitwear

- o Wrinkle recovery and crease stabilisation
- o High lightfast dyeing
- o Total Easy-care.

COST COMPETITIVE WOOL PROCESSING

Wool is more expensive than its competitors to convert to yarn and fabric. Typically wool converts to fabric at $35 to $120 per kilogram while its competitors costs are $10 to 35 per kilogram. The highest cost in processing wool to garment occurs in spinning and twisting. Wools competitors have advanced considerably in this area to wools competitive disadvantage. Additionally, most of Australia's clip is converted to top before blending with other fibres. The machinery used in these operations of scouring, carding and combing are unique to wool so warrant special attention.

As wool represents less than 3 per cent of the global fibre market, there is only moderate incentive for machinery manufacturers to specialise in wool. This program aims to form research partnerships with machinery manufacturers to encourage the application of new processing technologies to wool.

The goal of this program is to reduce the cost of converting greasy wool to woven fabric by 15 per cent and knitted fabric by 10 per cent through:

Machinery Innovations and Improved Process Efficiencies
Identification of inefficiencies in the processing pipeline and formation of research partnerships with companies and R&D agencies to develop or modify equipment that will provide productivity gains.

Building on Wools Natural Image
Seek increased market share by exploiting and preserving the clear advantages of natural image that wool holds over its competitors.

Transfer of Existing knowledge
Broaden the transfer of past R&D outcomes to countries judged by AWI to be strategically important to wool.

FUNDAMENTAL WOOL SCIENCE

Fundamental research underpins a whole range of technical developments in wool. Some of the less desirable attributes will be targeted, including photo-yellowing and poor wrinkle recovery of lightweight wool products that have restricted markets for wool.

Recent restrictions on use of after-chrome dyes increased the costs of production of easy care wool products. Environmental concerns over the use of Chlorine-Hercosett could threaten an important growing market for wool. These will also be targeted as easy care products currently use more than 45 million kg of wool per year and this figure is expected to grow.

The intractability of many of the key problem areas for wool means that new approaches are required to achieve solutions and these will only come through a more fundamental understanding of the fibre, its structure, physics and chemistry.
Our goal is to develop the new fundamental knowledge about the surface, structural and chemical properties of wool fibres.

Surface properties of the wool fibre

- Understand the considerable gaps in the chemistry structure of the proteolipid surface layer and the chemistry by which the components are bound together to facilitate development of techniques to manipulate the surface of wool.
- Gain new information to form the basis of new market opportunities for wool. For example, developing a new generation of improved low-add-on shrink-resist processes.

Mechanical properties of the wool fibre

- Enhance knowledge by establishing a database of information on fine structure (both chemical and physical) that can be used to evaluate the relationships between structure and fibre properties.
- Develop this information to form the basis of new market opportunities for wool. Stronger fibres will allow faster processing whereas more flexible fibres will give products with a softer handle.

The physics of wool processing

- Increase understandings of the interaction between fibres and wool fibres with the various working surfaces.
- Apply this knowledge to underpin technologies in improving processing efficiencies (carding-combing-spinning speeds), yarn and fabric quality and ultimately product performance (eg pilling and felting).

Whiteness of wool

- Provide a fundamental understanding of the photo and thermal stability of wool proteins.
- New knowledge that leads to the development of whiter, more light-stable wool will be applied to recapture lost sportswear markets and create new markets.

MARKETING PLATFORMS:

The following marketing platforms have been developed to help focus R&D outcomes to the market need and to deliver R&D outcomes to the market place.

Merino Super Soft:
In classic fully-fashioned knitwear, Merino is often by-passed for softer fibres, at one end of the price scale, cashmere, in the mid price points, viscose and viscose blends, and at lower price points acrylics. Consumers perceive wool as prickly in comparison to this range of products. In addition we need to soften the touch of Merino products to re-enter markets such as *intimate apparel, sleepwear, baby and infant wear*, and to enter new markets such as *active wear*, currently dominated by soft, fluid synthetic filaments and micro fibres. To achieve this we have developed a marketing platform called *Merino super soft*, a vehicle to pull together and develop projects designed to soften Merino fabrics across the different micron ranges and develop products with specific brands and retailers in mind.

Fields of Gold:
Merino fibre is yellow, and while it can be bleached, and treated with optical whitening agents, exposure to sunlight quickly yellows the fibre again. This restricts the sale of Merino in *knitwear*, particularly in early spring where light, bright colours are required for the fashion market to reflect the colour and beauty of nature. Cotton and synthetics can carry this type of palette well, being naturally white fibres initially, and as such Merino is overlooked for spring. In trying to re-enter markets for *baby and infant wear*, again we need Merino to have brilliant whites and to carry clean light pastel shades well. New markets in *gym wear*, *active wear* also need brilliant whites and fresh pastel shades. To deal with this limitation on colour we have developed our *fields of gold marketing* platform, which attempts to deal with bleaching and brightening of Merino substrates and developing new substantive dyes and permanent protection of the products from sunlight.

Winter to Spring:
In addition to losing market share on value, in ladies tailoring, Merino fabrics have also lost ground on aesthetic appeal. Colour has already been mentioned, but the new generation polyester, viscose and polynosic micro fibres introduced in the 90's offered the ladies market exceptional drape and softness. The arrival of Optim also known as Arcana enhanced the softness and drape of Merino, but currently, this is only available in blends. A marketing platform, *Winter to Spring*, incorporates this development, as well as Merino blends with other fibres such as linen, silk, viloft and micro fibres to give more drape, cooler handle and better colour, allowing Merino to re-enter the early spring ladies market.

Noveau Classique:
The logical extension to the *Winter To Spring* platform for ladies wear is *Noveau Classique* a platform to reintroduce classic looks, with a more modern aesthetic in terms of *touch, drape* and *fabric finish*, for Autumn/Winter season.

Summer in the City:
The development of a lightweight, fine, easy care, Merino shirt, led to the platform *Summer In The City*, extending the innovation to ultra lightweight tailoring for both men's and ladies markets. As well as being 30% lighter than normal, the fabrics drape like silk, and due to the process parameters involved are machine washable, without having been treated by any

specific chemicals. The tailoring of these fabrics will be soft, to give products that are smart enough for business, but with greater comfort for the wearer.

Total Easy Care:

Machine washable Merino, and Merino blends, which can be tumble dried with no or minimum iron properties are imperative in the modern market. There are exceptions to this, particularly at the luxury tailored, but in general, fabrics made from Merino, whether knitted or woven, should be capable of being cleaned at home and tumble dried, with minimum iron requirement. To satisfy this imperative we have various projects running in our *Total Easy Care* platform, wool rich suits/ trousers are already available in the market. 100% Merino trousers, with permanent crease, are in the final stages of commercialisation, with a clear strategy of penetrating the markets of North America to compete with cotton. 100% Merino jackets are being developed with a commercial partner in UK. For some years technology has been available to allow Merino knitwear to be machine-washed. However the North American market requires not only machine washable knitwear, but also tumble dryable. A current project total easy care in the USA, again linked with commercial partners including USA based retailers, and spinners and knitters, is developing this capability. Merino knitwear has only a 30% share of this large market, while cotton has 40% share, and the total easy care programme is designed to take share from the cotton and synthetic products.

Business to Business:

This platform is designed to target companies who provide their staff with corporate uniforms. Companies such as airlines, hotels, banks, retailers and travel agents. This market has become " wool poor" over the years for various reasons e.g. price, difficulty in care, durability of Merino, and appearance retention. In other words by adding polyester to the blend, not only does the price reduce, but also the durability of the product improves, as does the appearance (in terms of crease recovery, not aesthetics). The issue of price is beyond redemption, but on the assumption that *some* of the corporations would like to have at least *some* of their staff in the best quality outerwear, then it is worth dealing with the technical issues. The average corporate wardrobe is *two jackets and five skirts/trousers* and is required to last for *three years*. Research is being conducted to try to help fine Merino achieve the same level of abrasion resistance as a polyester/wool blend. In addition another project is attempting to significantly improve the wrinkle recovery of fine Merino, which is vital for the corporate market. This will also provide a basis for the *ultimate travel suit* in 100% Merino. Finally these projects with the aforementioned *total easy care* platform will give new opportunities for 100% Merino in the corporate wear market.

Dormez Bien:

Over recent years the bedding market has largely moved away from Merino products. However recent studies have proven that people sleep better in a Merino environment, as opposed to other products such as down or polyester. Under this platform a new generation of bedding products have been developed, using Merino fibre, including *total easy care* blankets, Merino filled duvets, Merino mattress covers and throws. Commercial partners have been sourced both in Australia, for the local and Asian market, and the U.K. for the European and North American markets.

Active Performance:
This sector is not only crucial in it's own right but also for its influence on the vibrant *"street wear"* market. The joint development with The Woolmark Company of *Woolfleece* is the first major success from this platform. Products in Merino are being developed for distribution through the highly acclaimed Australian *surf wear* brands. New fabrics are also being developed for *foul weather* use in for example *orienteering, sailing, and golf.* In addition *gym wear* is being developed in conjunction with the *Merino super soft* platform, where the influence of colour from the *fields of gold* platform will also be crucial. The *golf wear* market, a traditional bastion for Merino fibre is also targeted within this platform.

Natural Australia:
Merino and good quality cotton fibre are grown in Australia. Recently, successful completion of an AWI funded project, to allow short fibre Merino to be produced on the high speed cotton spinning machines called *Murata Vortex*, permits the production of Merino cotton blends on the cotton system at lower cost than the worsted system. This platform is designed to develop products such as *trousers, skirts, shirts, blouses, sleepwear and intimate apparel*, which can be produced by high volume cotton manufacturers.

Winter Warmth:
Developments in *smart textiles*, in this case heat conductive yarn, have created this platform. The first product to market will be a *heated sock*, where a retailer and manufacturer are in the final stages of development. The next product will be a *heated Merino blanket*, again with partners working in development, followed by *heated Merino gloves* and possibly *heated coats*. The interest from the commercial world in this technology is significant and we expect work to continue both on current products and in future products.

Forever Young:
Soft white fibres such as cotton and acrylic now dominate the baby and infant market. However the physical and physiological benefits and the comparative safety features which Merino offers developing infants, is significant and justifies a new range of innovative product development. This platform is also dependent on *Merino super soft*, and for colour and whiteness on *fields of gold*.

Natural Healing:
The AWI funded developments for Merino fibre in *non-woven* structures has led to the establishment of this platform. Merino fibre is a natural anti toxin, as well as the most absorbent textile fibre, as such it has a role to play in non-woven bandaging. Extensive trials are being carried out in hospital burns units, with both clinicians and a commercial pharmaceutical partner, to demonstrate these attributes in the treatment of burns victims where less re-dressing is necessary, and therefore less exposure to hypothermic shock for the patient. Application of

intelligent textile developments to this platform will allow the wound temperature and moisture content of the wound to be monitored without the removal of the dressing. Other opportunities to use Merino fibres natural anti toxin properties are being studied.

Dangerous Liaison:
Recent fabric developments enabling the production of high density Merino fabrics which are highly impervious to penetration of light, radiation, external physical pressure, and molten metal splash, opens up new market opportunities in the protective clothing market. In addition these fabrics are so dense, that the natural properties of Merino, combined with the lack of oxygen in the dense structure, that they have a very positive flame retardance quality. This platform is designed to develop and deliver this innovative group of fabrics into a highly specialised market.

Catch The Wind:
As in Natural Healing, the AWI funded *non-woven* projects for Merino fibre has allowed the establishment of this platform to use Merino fibre in environmental filters. This is a very large market for industrial textiles, and Merino fibre with its natural electrostatic charge in a non-woven format, is proving to be a very efficient filtration medium. Two industrial partners are actively working on the commercialisation of the initial project, whilst other filtration systems are being developed.

The consumers of today need information. It is not unusual to observe swing tickets, on garments of up to eight pages long, confirming, to the consumer the inherent benefits of the product. As a support to our marketing platforms and technical projects, AWI is funding a short 3-month program, to publish all the known benefits of Merino fibre, so that all producers of Australian Merino fibre are able to produce factual point of sale information highlighting the proven benefits of using Merino fibre.

As a facilitator and investor of wool R&D, AWI is looking for new and innovative ideas from any organisation around the world. Our primary role is to provide financial support to any project that has the potential to increase the usage and subsequent demand of Australian wool. This includes product development projects linking retailers to suppliers along the wool pipeline to assure the best quality wool products at the right price are offered to the consumer.

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Enhancing The Properties Of Wool By Chemical Engineering Providing Future Opportunities

PETER DUFFIELD

This paper will review the topic of "Techno" Finishes for wool. The first question that goes through one's mind when considering altering the characteristics of a fibre such as wool is why do it?

There is of course no consistent reply because it depends on who is providing the answer. From a sheep's point of view the answer is "What is wrong with my fleece as it is, evolution has spent eons developing this most complex and amazing fibre". Unfortunately a wool fleece is not necessarily the most appropriate form of human apparel.

From a consumer's view point the wool fibre is regarded as traditional, even old fashioned but its characteristics can also be very modern; easy care, stain repellent, warm, cool, bulky, light, comfortable, and robust. However, some of these attributes are mutually exclusive unless one can add some "technology".

From a retailer's point of view fibre content of the products that he sells is not very important but what is important is the marketing potential, which, for a given price, relates to the perceived advantages of his product, in comparison with his competitors'. Therefore, we need to look at how the wool textile manufacturer can use techno finishes to give the consumer what he wants and the retailer a competitive advantage.

"TECHNO" FINISH

However, it is first necessary to provide a definition of "Techno" finish. In the most general sense it is any chemical finish, other than dyes, that is applied to wool in fibre, yarn, knitwear or woven form and that will change or enhance one or more attributes of the product.

Techno finishes fall into two groups; those that provide improved performance, either for the consumer or the processor and those that improve the product's aesthetic properties. Of course, combining both attributes is sometimes also possible. Some of the properties that will be addressed in this paper include:

- Performance
- Handle

- Protective effects for the wearer
- Comfort
- Visual effects
- Well being

There are two rules that should be observed when applying techno finishes. These may be applied at various stages throughout the processing pipeline and the earlier in the pipeline they are applied the more they can affect the processing characteristics of the fibre. This is Rule Number 1.

Rule No 2 follows directly, if the techno finish is applied as late as possible in the processing sequence, the more chance it has of maintaining its effectiveness.

PERFORMANCE

Easy Care

Technologies are available for producing Easy Care wool products via treatments applied at different processing stages:

Tops - around 30 continuous processors of tops globally

Loose fibre - 4 loose fibre processors globally

Yarn - treatments are not recommended, because of levelness and consistency issues

Woven fabric - treatments rely on polymer application or the use of chlorine/Hercosett yarns followed by a polymer applied to the fabric

Garments knitted garments are treated by various means, including Simpl-X from PPT

Woven garments - generally not processed, although a company in Thailand is applying a new process for total easy care, developed by The Woolmark Company

Pilling

At the last count there were over 25 factors identified that contribute to pilling in knitwear and wovens. However some factors are more critical than others. Fibre diameter and fibre length profile have a pronounced effect, especially if they are bimodal. Soft yarns and open structures lead to pilling. Unfortunately these also confer the highly desirable attribute of softness. Blends with synthetic fibres increase pilling, as do some resin treatments. Conversely degradative treatments such as oxidative and enzymatic processes decrease pilling. The latter have been used in bio-wash finishing to improve the surface appearance of worsted spun knitwear. Poor finishing or reduction of inter fibre friction through over-softening can also make pilling worse.

The remedies currently adopted usually involve avoiding the above negative factors but unfortunately this is not always possible. A techno finish that can improve the pilling performance of knitwear is often needed preferably for application at a late stage in manufacturing. The currently available processes rely upon resins that bonds fibres together and prevent fibre migration, these systems can lift pilling grades by one to one and a half points but at the expense of handle, which can be made firmer.

The Woolmark Company is currently working with Australian Wool Innovation to investigate the how pilling can be reduced with minimum effects on aesthetic properties.

Wrinkling

Wool naturally performs well in shedding wrinkles and creases but this attribute can be enhanced to give "wear from the suitcase" performance. A combination of yarn engineering (fibre selection and twist ratios) and a special polymer treatment for the yarn yields fine gauge knitwear that can be worn straight out of the suitcase. This project requires special development co-operation between knitter and spinner.

HANDLE

Several approaches are available to improve the handle of wool products and some of the more important ones will be reviewed.

Soft Lustre

Based on an easy care process is Soft Lustre. This technology relies on a continuous top pre-treatment followed by a special silicone polymer. The pre-treatment stage is more severe than conventional easy care processing and removes the scale structure, without damaging the interior of the fibre, to create a smooth surface capable of reflecting light in a similar way to mohair. At the same time the fibre diameter is slightly decreased and, because the silicone polymer decreases inter-fibre friction, any fibres protruding from the surface of Soft Lustre knitwear move easily back into the structure. Thus fibre ends exert little or no pressure on nerve endings in the skin and generate a much lower sensation of prickle in wearers.

Because the treatment is so intensive a side effect is that the Soft Luste treated fibre is also suitable for Total easy care knitwear such as hosiery and underwear. An important market for this product is China, where wool underwear is very popular.

Basolan® 88

Basolan 88 generates a different, bulkier softness to wool than the soft lustre process. It is less costly to carry out but generates a product that is "Hand Wash" only. In many instances this is entirely acceptable and the technology is being increasingly widely adopted.

PROTECTION

Odour Control

The wool fibre is already good at absorbing odours but this property can be enhanced by applying the Deolaine molecule to the fibre surface. The Deolaine molecule is environmentally neutral but has a tremendous capacity for absorption including the products that create body odour on the skin as well as those resulting from bacterial action on the garment. It is re-charged automatically during washing. Being firmly attached to the wool fibre it is also durable. Even after 10 washes it still works at 90% efficiency.

Stains

Wool performs very well in terms of having low staining and soiling propensity. However, for some application these properties require enhancement. There are three approaches to dealing with stains.

Keep the stain on the outside of the fibre - STAIN RESIST
Encourage the stain to penetrate a layer that is easily removed during washing - STAIN RELEASE.
Inhibit the stain penetrating the fibre - STAIN BLOCKING

These approaches differ considerably in the chemicals that are used to achieve the effect:

- Satin resist — Flourocarbon
- Stain release — Flourocarbon that flips to give a hydrophilic surface
- Stain block — Anionic + fluorocarbon

Traditional forms of stain repellents used hydrophobic layers such as waxes on cotton fabric and worked on the premise that most stains are water based. An additional benefit was that water repellency was also generated. However, such finishes were unfortunately not effective with oil based stains and not durable to washing/dry cleaning.

Silicones and fluorocarbons became available some years ago and, because they lower the surface energy of the fibre, offered highly hydrophobic surfaces. Silicones were generally only good for water-based stains, as they tended to soil rapidly with oil based stains. They were therefore ideal for ski-wear and similar products. Fluorcarbons however are capable of lowering the surface energy of a fibre so far that even oils such as petrol cannot wet the surface. 3M and Dupont have been the global market leaders with their Scotchgard and Teflon product ranges. Note these are brands which cover a range of finishes, thereby offering many possible performance advantages to various wool products. Versions that are durable to machine washing and dry cleaning and which do not require heat treatment after cleaning to reactivate the repellency are now available. For knitwear the high curing temperatures of 130°C and higher were formerly a problem but even air-cure versions are now available.

Flame Retardancy

There are various mechanisms by which the flame resist (FR) properties of wool can be enhanced, so that the fibre can meet the most stringent requirements for textile applications. These are to be found in transport, e.g. airline furnishings, and for protective apparel.

Topical treatments simply cover the fibre with a FR layer that prevents oxygen getting to the fibre, so inhibiting combustion. These treatments often seriously effect fabric handle and are mostly used in building materials.

Other mechanisms use char formation to limit flame spread. As you may know, untreated wool forms a char during combustion and the most effective treatment simply enhances the char layer formation. This mechanism is the basis of the Zirpro process for Wool. Zirpro can be combined with easy care finishes to yield extremely effective and durable FR finishes for transport, military and institutional products.

The third method uses chemicals, such as tetra-bromopthallic anhydride, which decompose in heat to release bromine which displaces oxygen from the fibre surface and reduces combustion. These are often used in situations where low smoke emissions are required, often in combination with Zirpro.

COMFORT

Static Control

Disperstat® products are designed to combat static build-up in dry climates. Static can, at best, lead to fluff build up or cause discomfort through garment cling but it can also create operational problems in the computer and the petroleum industries. Disperstat is well established and known in the carpet industry but a suitable product is now also available for apparel.

It is applied as an integral part of a shrink resist process and works by preventing static build up rather than by current leakage. The effect is dramatic, reducing static levels to well below the threshold for human sensitivity. It is durable to machine washing and has no effect on wool's natural properties.

VISUAL PROPERTIES

In addition to the bright and lustrous effects that are generated with Soft Lustre and Basolan 88, there are other developments that can generate novel visual properties.

Lacquered effects are new and popular with consumers in Europe. Aged or washed-out colours are also undergoing a revival in popularity. Such effects were developed ten or eleven years ago, particularly for cotton but technology was also developed for wool to give knitted garments a very casual appearance. The pigment or sulphur dye technology can be applied to Easy Care knitwear in conventional garment dyeing machines.

More extreme visual effects can be achieved by embedding particles on the fibre surface of wool garments. These can generate a bright, glittery appearance or with reflective particles or something that is more subdued with minute glass beads or translucent particles.

Well Being

There is new technology in the encapsulation of many types of agent that can be applied to wool textiles, as well as other substrates. The Woolmark Company has been working in this area and developed Sensory Perception Technology (SPT). The exclusive agent for SPT in India (including Bagladesh and SriLanka) is Resil Chemicals. The technology is applicable to both apparel and interior textiles and works by chemically bonding capsules to the substrate. As the particles are broken in use there is a time release of their contents.

Aromatherapy sessions usually involve expensive time consuming private consultations. By combining micro-encapsulated essential oils such as lavender, sandalwood, etc with Total Easy Care (TEC) wools it is feasible to create machine wash tumble dry wool knitwear that creates personal aromatherapy sessions during wear to enhance well being.

Aloe Vera is already well known as a skin moisturiser and now, by using the latest micro-encapsulation technologies in conjunction with TEC treated wool, it is possible to create wool knitwear which slowly releases Aloe Vera during normal wearing. Imagine fine merino knitwear that gently massages Aloe Vera into the skin during wear to enhance comfort to new levels.

Both these processes work through attaching the encapsulated active ingredients to the TEC fibre surface. A combination of exhaust application conditions and a special binder give softness and durability to machine washing, 5 to 10 cycles. The treatment can only be applied at the garment stage because processing such as spinning and gilling would destroy the capsules.

Marketing

It is vital that the products developed through "Chemical Engineering" of wool reach the marketplace and generate sales. This depends on the consumer recognising the added value of the new products. To communicate these benefits to the consumer special tickets are available.

CONCLUSION

I hope that this paper has demonstrated that a traditional fibre like wool can also be made "high-tec", through the application of innovative chemical technologies. Only by the adoption of these developments will the fibre continue to be relevant in the textile market.

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Polypropylene Staple Fibre For Non-conventional Applications

SR VENGSARKER & VIKAS GUPTA

Historically Polypropylene (PP) Staple Fibre is extensively used in floor carpets and in recent times in Hygienic products and Geo textiles. In our country Polypropylene Geotextiles have received serious attention due to importance being given to infrastructure development.

Polypropylene fibre is unique amongst all synthetic fibres. It has lowest specific gravity giving rise to very high volume to weight ratio, and the fibre is inert to action of most acids, alkalies and solvents. The fibre has excellent warmth and resiliency. Its moisture wicking characteristic from the surface of the skin to outside is unique. It has therefore un-matched special end-use applications.

We have established in our country good usage to Polypropylene fibre in woven filter Fabrics for chemical filtration, for Drinking Water Filtration Cartridges including use of Anti-Microbial fibre, in Asbestos Sheets/Pipes, for use in the construction industry, as a Fire Resistant fibre, for use in low cement castable refractory, etc. Our efforts to use PP Sliver after braiding for export bags and for using woven lightweight fabrics in Process Houses and also making Thermal Innerwear to use at high altitudes have met with good success.

There is no doubt that some of the applications mentioned here are in vogue the world over. However, to introduce these applications in our country and in our conditions, a lot of efforts have gone in. These applications are:

- Use of short Cut PP Fibres
  - In Construction Industry
  - In manufacturing of Asbestos Sheets & Pipes.
  - In the manufacture of Low Cement Castables.
- Woven Filter Fabrics.
- As Antimicrobial Fibres for Hygiene Products.
- As Fire Resistant (F.R.) Fibre.
- In Filler cord used in Jumbo Bags meant for Exports.
- In Polypropylene Fabrics used in Process Houses.
- In 100% knitted fabrics for Thermal innerwears.
- Polypropylene Tow for Hair Additions such as Wigs.

Short Cut Polypropylene Fibres For Construction Industry

Polypropylene is the most widely used type of fibre reinforcement in concrete. PP fibres are chemically inert and stable in the alkaline environment of concrete. Fibre bonds in concrete matrix through interfacial adhesion and mechanical anchoring.

The Fibres are produced in cut lengths of 6mm, 10mm or20mm. The Fibres are uncrimped. The fibres are dressed with spin finish oils to provide excellent wet ability and dispersability in water. Typical fibre properties are as follows:

1. Raw Material	:	Polypropylene
2. Specific Gravity	:	0.908
3. Fibre cut length	:	6mm, 10mm or 20mm
4. Fibre Denier	:	2.5, 3 or 6
5. Tensile strength (Min.)	:	345 MPa
6. Fibre Cross Section	:	Circular
7. Softening Temperature	:	145° C approx..

The Fibres shall conform to the requirements of ASTM C116-89.

Table 1 Typical Usage

Application	Dosage	Fibre Cut Length (mm)	Fibre Denier
Plaster or Mortar	125 gms/Cement bag	6	3 or 6
Concrete	910 gm. Per cubic mtr.	10 & above	3 or 6

Table 2 Fibre Count And Strength

Both fibre count (no. of fibres in cross-section) and fibre Tenacity play an important part in the selection of a particular fibre Denier and Length.

Fibre Denier x Length (mm)	Tenacity (gpd)	Tenacity (MPa)	Fibre Count
6 D x 6mm	4.5	360	246 million
6 D x 12mm	4.5	360	123 million
6 D x 18mm	4.5	360	82 million

PP Fibres are used to inhibit the formation of small Cracks which can occur through plastic shrinkage, premature drying and early thermal changes. Advantages of adding Polypropylene fibres to any Cementious Mix are :

- Drastic Control of Shrinkage Cracks
- Reduction in Settlement Cracks
- Improved Tensile and Flexural Strength.
- Improved Water and Chemical Resistance.
- Improved Impact & Shatter Resistance.

- Decreases wastage of material by increasing cohesiveness
- Prolongs service life of overall structure.
- Compatibility with all Mix Designs and Mixtures.

Principal Uses of Fibre concrete are:

- Concrete Slabs
- Pavements
- Driveways
- Plasters
- Krebs, Pipes, Overlays
- Water retaining structures
- Heavy Industrial Floors

The fibre shall be added to concrete at the desired ratio. After addition the Concrete must be mixed for 4 to 6 minutes at mixing speed of about 75 revolutions per minute to properly disperse the fibre throughout the mix.

TEST DATA ON THE USE OF PP FIBRE IN PLAIN CONCRETE (FROM U.K. SOURCE)

Following improvements have been observed using PP Fibres:

1. Specific Shrinkage Cracking : 95% reduction in crack area
2. Bleed : 55% reduction in bleed rate
3. Change in height : 42% reduction in plastic settlement
4. Compaction Factor : 01% increase in workability
5. mpact Resistance : 67% increase in impact resistance
6. Abrasion : 11% increase in abrasion resistance
7. Surface Permeability : 19% reduction in surface permeability
8. Compression Strength : No change

The popular durability test for evaluating the fibre in concrete is the ageing test in which fibre reinforced concrete samples are stored in a lime-saturated water maintained at elevated temperatures. The elevated temperatures levels vary from 50° C to 80° C. To examine the effect of Alkaline Lime conditions (pH 13-14) and at temperature of 50° C experienced in Concrete, Polypropylene Fibres were subjected to this condition.

Table 3 Denier Polypropylene Staple Fibre

Test Property	Normal (Untreated)	Treated
Average Denier	2.94	2.94
Average Tenacity (gpd)	5.3	5.2
Average Elongation (%)	35.8	34.8

Polypropylene fibre is not at all affected by the alkaline conditions mentioned above.

Most Concrete Floors both internal and external, are subject to abrasion through trafficking of vehicles such as forklift trucks, cars and lorries, Addition of PP fibres control the bleed water migration in a concrete mix, reducing the possibility of segregation of fine cement and sand particles. This will give more efficient hydration of cement, and combined with the improved bonding of the Cement Matrix achieves a tougher, more durable concrete surface. In addition, the surface will have lower water/cement ratio than non-fibre concrete thus increasing abrasion resistance.

TRIALS CARRIED OUT ON FIBROUS CORBEL SPECIMENS

The corbels can be defined as short and deep cantilevers projecting from precast concrete elements or gantry girders. These structural elements are commonly used in precast concrete construction to transfer loads from slabs or beams to columns or walls. They are generally kept very small in dimension and are fairly heavily loaded.

PP Fibre (6 Denier x 20mm mength) dosage rate of 910 gm per Cu. Cm was done in fibrous Corbels

Table 4

Type of Specimen	Compressive Strength of Cube $N.mm^2$	Split Cylinder Tensile Strength N/mm^2	Flexural Tensile strength N/mm^2
Non-Fibrous (Control)	32.30 31.60 *32,58 32.88	4.95 4.12 *4.44 4.25	1.70 2.20 *2.0 2.00
PP Fibre "reinforced"	36.10 35.00 *35.30 34.81	4.25 4.95 *4.57 4.52	2.10 2.40 *2.4 2.60

** Average value of three specimens for each strength property.*

BASIC CONCRETE STRENGTH

The increase in basic strength parameters such as Compressive strength, Split Tensile Strength and Flexural Tensile Strength of Fibrous control specimens are as mentioned below:

Compressive Strength	-	8% increase
Split Tensile Strength	-	3% increase
Flexural Tensile Strength	-	20% increase

CORBELS

The maximum increase in Initial Crack Load, Ultimate Load and Cracks is as mentioned below:

Initial Cracking Load	-	17% increase
Ultimate Load	-	19% increase
Cracks	-	75% increase

CRACKS

As desired, there was a reduction in crack width, average crack spacing, maximum crack spacing and height of flexural crack in all fibrous corbel sections. The optimum reduction in these structural characteristics was as mentioned below:

Maximum Crack width	-	40% decrease
Average Crack spacing	-	45% decrease
Maximum Crack spacing	-	32% decrease
Height of flexural crack	-	38% decrease

Critical Areas of Application in which PP short Cut Fibres can also be used are:

- Earthquake Prone Zones
- Areas subjected to Vibration
- Railway Sleepers

SHORT CUT POLYPROPYLENE FIBRE IN THE MANUFACTURING OF ASBESTOS CEMENT SHEETS AND PIPES

The industry uses imported Chrysolite Asbestos Fibre. Such A.C. Products have problems of cracking during handling/transportation and also problems of health hazards.

If PP Fibre is used, the Asbestos Fibres can be reduced in the mixtures to as much as 4-5 times PP Fibres and the strength of the PP product is equal to or higher than 100% Asbestos fibre product. Impact Strength shows considerable improvement and the side cracks during transportation are also reduced.

2.5 Denier x 10mm length un crimped PP Fibres are generally used for Asbestos Sheets and 20mm length PP Fibres are used for Asbestos Pipes. Pilot Plant Trials were carried out in a Research Organization attached to a big Cement factory and 6mm thick Asbestos Sheets were prepared using 2.5 Denier x 6mm length uncrimped natural white PP Fibres. The test results on the sheets are reproduced below.

PP FIBRE GRADE 2.5 Denier x 6mm Nat white, Uncrimped. Sample size 8"x 3"

Table 5

Raw Materials (%)	Control	Sample B (Without CaCo3)	Sample D (with 5% CaCo3)	Sample E Imported
Cement	65	63	63	63
PP Fibre	0	2	2	2
Pulp	5	5	5	5
Silica Sand	30	30	30	30
Properties				
Water Curing 7 Days:				
Impact Strength (Domestic)	1.515	3.586	3.528	3.433
Density (gm/cc)	1.55	1.393	1.426	1.427
Water Absorption (%)	26.6	31.5	29.9	30
MRT (kg/cm²)	92	70	79	87
MRA (kg/cm²)	98	92	99	109
Water Curing 28 Days				
Impact Strength (Domestic)	1.57	3.69	3.60	3.62
Density (gm/cc)	1.574	1.424	1.414	1.424
Water Absorption (%)	25	30	30.6	30.1
MRT (kg/cm²)	114	99	98	96
MRA (kg/cm²)	118	126	126	121

MRT: Modulus of Rupture w.r.t. thickness of sheet (6mm thickness)
MRA: Modulus of Rupture w.r.t. density (this is taken at 1.6)

The conclusions drawn are as under:

1. Density reduces and water absorption increases with addition of PP Fibres.
2. MRT values of samples marked 'B' & 'D' show 5% increase over control sample.
3. No improvement in impact strength values is seen from 7 days to 28 days of curing.
4. Impact strength is nearly 2.5 times the control sample and this is a major gain.

Incidentally, it requires to be mentioned here that we have successfully developed and exported 2.2 Denier x 6mm PP Fibre grade with higher Melting Point of 172° C by use of Koylene S 8030 grade. This will help curing the cement sheets at 170° C for about 8 hours as required.

For asbestos pipes manufacturing company a typical usage of PP fibre is practiced as under:
A batch of 1300 kg comprises of:
1100 kg Cement/193 kg Asbestos fibre/7 kg PP fibre (0.53%)

USE OF SHORT CUT PP FIBRES IN LOW CEMENT CASTABLES

The low cement Castables are generally very dense in their structure. While these kind of castables refractory are heated up from the ambient to high temperature in their actual application, it is necessary to have some channels for evaporation of moisture which is

introduced during the initial mixing stage. Otherwise, there will be chances that the refractory will generate steam inside the body as the moisture will not have much access to come out. PP Fibre helps in forming these channels by melting at low temperature below the boiling point of water and thereby helps in the installation of low cement castables.
PP Fibres are added during the dry mixing of refractory castable mix and during mixing process the fibre get evenly distributed. The low cement castables are generally having strength above 700 kg./sq. cm., when PP fibres are used. Little dose of PP fibres does not however affect the strength of the material.

WOVEN FILTER FABRICS

In our country the use of Woven Filter Fabrics is commercialized to a large extent. This is because Polypropylene Fibres offer excellent chemical resistance to most Acids, Alkalis and Solvents. In this respect none of the other commonly used synthetic fibres offer any competition to Polypropylene. Such Filter Fabrics are used for both air filtration and liquid filtration.

Liquid filters remove solids from suspensions in the form of filter cake leaving clear liquid or a solution. The efficacy of filter fabric reflects in the ability to prevent solid material from passing through while giving an even flow of liquid. Hence, the weaving construction and the fabric weight assume great importance. Plain weave gives low porosity and excellent particle retention but may cause clogging in certain situations.

Industrial Filter Fabrics made of 100% Polypropylene spun yarn fulfill satisfactorily all the requirements such as Air permeability, Abrasion Resistance, Breaking Strength and Breaking Elongation.

For a given Filter Fabric, the main properties affecting the filtration characteristic of the filter fabric are Air permeability, Weave & Fabric sett. The most common yarn count used in Filter Fabrics is single 15s and doubled (from $2/15^S$ to $6/15^S$Ne).

Table 6 Typical Fabric Constructions

Details	1	2	3	4	5	6	7
Count of Warp & Weft (No)	$2/15^S$ x $2/15^S$	$2/15^S$ x $2/15^S$	$2/15^S$ x $4/15^S$	$2/15^S$ x $4/15^S$	$2/15^S$ x $4/15^S$	$2/15^S$ x $6/15^S$	$2/15^S$ x $2/15^S$
Ends/Inch x Picks/ Inch	52 x 36	76 x 36	76 x 30	93 x 28	123 x 24	123 x 23	130 x 58
Weave	2/2 Twill	2/2 Twill	2/2 Twill	2/2 Twill	2/2 Twill	2/2 Twill	4/4 Twill
Weight (gsm)	310	380	460	540	630	700	700
Application – Dust Collection Bags - Dry Filtration - Wet Filtration	In chemical Filtration, In Bulk Drugs and Intermediates & Dyes Industry						Chemical Filtration

Typical Conditions for usage :

- Upto 90° C. temperature for Dry filtration
- Upto 120° C. temperature for wet Filtration
- Most preferred for Alkaline and Acidic conditions.

Presently about 80 to 100 te. per month Polypropylene Staple Fibre is being used to spin 15s and occasionally 24^s Ne 100% Polypropylene Spun Yarns on Cotton Spinning system for making Filter Fabrics.

Filter Fabrics are going into the following Industries:

1. Metal Plating Industry (Woven Fabric used on the disc filter).
2. Pigment and Dyestuff Industry.
3. Inorganic & Organic Chemical Industries.
4. Drugs & Pharmaceutical Industry
5. In Paints & Varnishes Industry.
6. Oil Industry.
7. In Cement manufacturing Industry for dust collector bags.
8. Fertilizer Industry

Typical Test Report of a Filter Fabric produced out of 2/15s x 2/15s Ne yarn (100% Polypropylene Spun) is given below:

1. Weight per sq. metre gms (IS : 1964-2001)	:	400.1
2. Thickness mm (ASTM D-1777)	:	1.03
3. Breaking Strength kgf (Strip Size 20 x 5 mm)(IS : 1969)		
Warp	:	363.
Weft	:	180.1
Elongation at break %		
Warp	:	47.1
Weft	:	30.3
4. Air Permeability $m^3/m^2/min$. at 20mm Water Column.	:	2.3
5. Water Permeability $l/m^2/sec$. At 10 cm Water Column	:	>6.0
6. Bursting Strength kg/cm^2	:	40.7

ANTI-MICROBIAL PP FIBRE FOR HYGENIC APPLICATION:

Anti-Microbial PP Fibre grade has large application scope. Such a fibre can be used in drinking water filtration cartridges. Such PP Fibres exhibit anti-bacterial activity towards the most common harmful organism, primarily Staphylococcus Aurous and E-coli. The typical applications for such fibres in short cut lengths are in Stables, Cow Sheds, Poultry runs, Food (Cold) Stores, Hospitals, Water Treatment Plants, Sewage Treatment Plants etc.

A patented composite, which is essentially a very stable compound of Silver, is injected along with Polypropylene Granules during the manufacture of Polypropylene fibre. The composite is uniformly distributed throughout the Matrix of the fibre. Polypropylene Fibres will thus have an effective Anti-bacterial activity that will last its entire lifetime (i.e. nearly 50 years).

The Anti-microbial Composite used has low toxicity, is non-irritant, non-sensitizing and non-mutagenic. It also meets requirements of BGW and FDA for Food Contact Applications.

2.5 Denier x 51mm Natural white PP Fibre Grade containing 500 ppm of Anti-microbial Composite (Master Batch) was produced and this fibre was converted into "Roving" on spinning system. This Roving was used in Filter Cartridges Make-up as shown below:

Cartridges Make-up

Sleeve
↓
Spun-bonded PP
↓
Impregnated Active Carbon (0.2% Silver)
↓
PP Roving (ANTI-BACTERIAL)
↓
Carbon (Different mesh Sizes)
↓
Spun-bonded Cloth

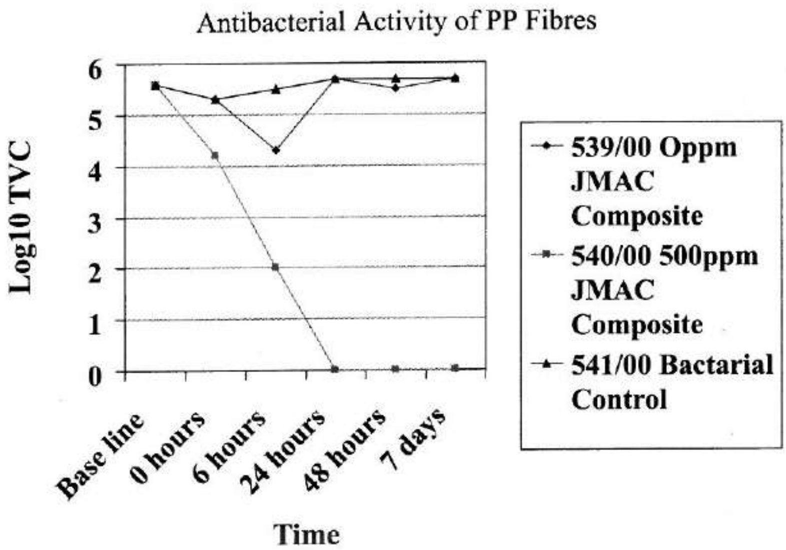
The Anti-Microbial Composite provides rapid and significant Anti-bacterial activity and will not allow any bacterial growth or fouling to take place. In other words, such a material will not allow the growth of slime formation especially when the water filtration unit is not in operation for a longer time.

In place of "Roving" we have also supplied "Dref-2 yarn" for this application since in case of Dref yarn the yarn surface is twisted very loosely thereby providing good water filtration. Dref-2 yarn is becoming more popular than the conventional Roving.

The effect of an Anti-microbial activity was tested abroad on the following 3 samples:

1. PP Fibre containing 500 ppm of Anti-microbial Composite
2. PP Fibre without Anti-microbial Composite
3. A Bacterial Control Sample

The Anti-bacterial activity of PP Fibres can be seen from the enclosed graph.**(GRAPH 1)**



Following Conclusions are drawn:

1. Results show that the bacterial inoculum in the water survive and grows over the test period. This growth is probably due to micronutrients present in the water. Any reduction in count in the samples with the PP Staple fibre must be due to activity from the material and presumably the composite. The challenge organisms are water/faecal borne E-coli and skin borne staph. Aureus and are typical of those encountered when the material is to be used.

1. The sample of PP staple fibre containing 0.5% Composite show rapid antibacterial activity. This indicates rapid silver ion release from the surface of the fibre when a liquid film is present. Any moisture present when the fibre is in use would have the same effect. This demonstrates in the laboratory surface activity of the PP staple fibre.

2. The sample of PP staple fibre without composite shows some inherent antibacterial activity. This may be due to release of residual free monomer. The reduction in the challenge inoculum appears to reach a limit within 6 hours exposure. The degree of activity is much reduced and slower compared to the antibacterial activity exerted by the fibre containing the anti-bacterial composite.

FIRE RESISTANT (F.R.) PP FIBRE GRADE

F.R. Master batch can be injected during the fibre production and a uniformly distributed F.R. Master Batch in the fibre Matrix can be achieved. The potential for the F.R. Grade PP fibre in our country is very well accepted for applications such as non-woven carpets, wall covering (in cinema halls), in aeroplanes etc. In plastics FR grade is used for moulded seats at Olympic Stadiums and also in very big Parks in Europe.

We have received imported FR Master Batch with the following typical specifications:

1. Appearance	:	White Granules
2. Melting Point	:	130° C.
3.Flow Velocity (MFI)	:	1.0 gm/10min.
4. Bulk Density	:	Around 1.25 gm/cm³.
5. Ingredients	:	Combination of Antimony & proprientary Halogen derivatives

6.Good Filterability & high thermal stability.

The above Master Batch was injected at 4%, 6% & 7% levels on the weight of PP granules. The flammability of fibre samples was tested to BS-3119 (Vertical Flame Test) and ASTM D-2863 (limiting Oxygen Index LOI) methods. Test Results on fibre samples with 7% Master Batch are given below:

Table No.7

BS-3119	**ASTMD-2863**
Char/Void length : 8.8cm	
After flame (Sec.) : Nil	LOI : 31.4
After Glow (sec.) : Nil	

Test Values of L.O.I. At different percentages of F.R. Master batch are also given below:

		L.O.I.
5% F.R. Masterbatch	:	27.6
6% F.R. Master Batch	:	29.0
7% F.R. Master Batch	:	31.4

Minimum desirable is 26.0

It is recommended to use 7% FR. Master Batch since even by Naked Flame Test the fibre does not hold any Fire or the Flame.

FILLER CORD

Polypropylene Jumbo bags are exported to western countries and such bags should also have Polypropylene braided sliver on the top of the bag. Regular supplies of Sliver in 100% Polypropylene and in 0.12 0.14s Hank are manufactured and used after braiding for this purpose. In this way Jumbo bag has 100% Polypropylene material. The bags are generally used for transportation of chemical powders.

Use Of Polypropylene Fabrics In Process Houses:

Polypropylene Fabrics produced out of spun yarn have a high Abrasion resistance, Low Density and negligible moisture. Also, such fabrics are inert to most Acids and Alkalis. The fabrics do not have tendency to absorb dyes normally used in dyeing of Natural and Manmade Fabrics.

Woven fabrics were made out of 2/24s Ne Spun Yarn (100% PP) and such fabrics were test-evaluated in Process houses during dyeing and printing as described below:

As Back Grey during Table Printing:

The Printing table is usually first covered with a woolen Namda type fabric to form a soft base and is covered by a cotton back gray to minimize the damage to the costly base woolen fabric and to increase its useful life. During printing the excess dye along with other ingredient of the paste will pass through the fabric to be printed to an extent depending on its porosity and construction. The chemicals passing through on to the cotton back gray e.g. disperse dye and acids in printing of polyester degrade it and the cotton back gray fabric has to be replaced after every 10-15 days.

To overcome this problem use is suggested of a polypropylene staple yarn fabric having 32 ends and 28 picks/inch (150g/m^2). The polypropylene fabrics being hydrophobic and having high resistance to acids has a much longer useful life of nearly 10 times that of cotton fabric.

As Back Grey Fabric In Steamers and Agers

Polyester fabrics printed with disperse dyes (500-600m) are put in a Pressure Steamer/Ager for 30 minutes. The printed fabric is threaded on a star frame type holder with an alternate layer of cotton/jute fabric. The separation of layers of printed polyester fabrics avoids colour mix-up and staining of the white portions of the printed fabric. The cellulosic separation fabrics (Back grey Fabrics) get considerably degraded during high pressure steaming due to hydrolysis oxidation and have to be replaced frequently. A Polypropylene staple yarn fabric of loose/open construction (20 ends and 18 picks/inch, weight 90 g/m^2) is suggested as replacement of cotton back grey fabrics. Polypropylene staple yarn fabric has a useful life of at least a month. The life of cotton/Jute fabric is not more than 5 to 7 days.

As leader/cheda fabric on a Jigger

Cotton grey fabrics of 6-8 m length are used as leader fabric at both ends of a lot of cotton or blended fabric to be dyed on the jigger using vat/sulphur/reactive dyes. The cotton leader and pieces also take up the dyes and are difficult to be reused. Polypropylene staple yarn fabric used in first application is suggested as replacement and due to lack of affinity for the dyes used, the stained pieces of Polypropylene Staple yarn fabric can be washed and reused repeatedly.

During these application trials in various dye-houses it is established that the initial high cost (nearly 3-4 times) of Polypropylene Staple yarn fabric is more than balanced by its much longer useful life compared to cellulosic fabrics.

The techno-economics in all the above application is thus very much in favour of Polypropylene Staple yarn fabrics. A number of progressive textile process Houses have already started changing over to the use of the new locally available polypropylene staple fibre fabrics for above uses.

THERMAL INNERWEARS:

Polypropylene is a fibre, which is adept for the realization of undergarments for use in cold weather condition, and during varied activities. Its insulating capacity is high, its permeability of vapour is excellent, its capillary transport (wicking ability) is optimum and its speed of drying is elevated one, thus maintaining the insulating ability of the polypropylene articles.

Table 8 Test Proerties Of Thermal Innerwear Sample

Test property	100% Acrylic	100% PP	75/25 PP/Wool	50/50 PP/Wool
Weight (gsm)	148.4	196.9	193.9	204.9
Insulation value (Thermal conductivity) clo value	0.84	1.26	1.13	1.03
Pilling Rating	2-3	2	2	2

50/50 PP/Wool Thermal Innerwear Fabrics have been supplied to high altitude army personnel and the same have been found to perform very satisfactorily.

POLYPROPYLENE TOW FOR USE AS HAIR ADDITIONS:

Polypropylene Tow (both crimped and un-crimped) is used for this application. The colour shades generally selected are Black, shades of Grey and Brown.

Following are the typical specifications of Tow product:

Individual Fibre Denier	:	40
Tow Denier	:	200,000
Filament Cross-section	:	Trilobal (for Sparkle effect)
Avg. breaking Tenacity (gpd)	:	2.3
Avg. Breaking Elongation (%)	:	175

Both lightly crimped and un-crimped tows are used.

The Tow so produced undergoes minor processing before packing as Hair Addition material for Export market in the African continent.

SUMMARY

In today's changing scenario Polypropylene staple fibre is assuming lot of importance amongst the class of synthetic fibres not only for the well-established conventional applications but also for totally new un-conventional applications described in this paper. This is possible only due to un-matched fibre properties of Polypropylene staple fibre. If this thinking gets converted into action, we are sure that there will be many more plants of PP which will have to be installed in our country in the coming decade.

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Innovation In Spinning Technology

— R CHATTOPADHYAY

Spinning is the process by which short staple fibres are transformed into a regular strong yarn. The technique of transforming a bunch of fibres into yarn, which consists a number of process steps, was developed long ago. But in those days the entire operation was manual and therefore depended to a large extent on the skill of the individuals involved. With time people mastered different manual operations, refined and improved them and started producing excellent fabrics. As the demand grew due to rising population mass scale production means had to be adopted. Industrial revolution in England started and mechanization of the operations were resorted to.

What Is Innovation

A mere improvement in the design or process, which is obvious, cannot be termed as innovation. Developments that has made or likely to make a significant impact either on the quality of the product or the process in terms of its economics, simplicity, ease of operation & maintenance, environment protection can only be called as innovation as shown in Fig.1.

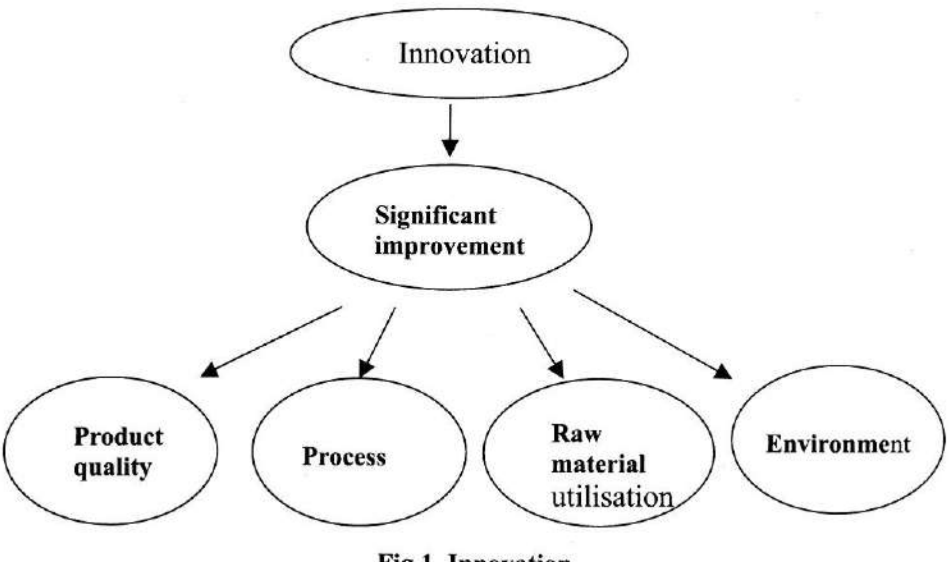

Fig.1. Innovation

There are two activities in Research and Development. While most research and development (R & D) projects deal with slight changes of an existing product (optimization), few actually create innovative new products (innovation) [1]. Therefore, the issue in defining and selecting projects for R&D requires a decision to innovate or to optimize.

TYPES OF INNOVATION

Innovation in staple fibre spinning could be in three different areas viz. in technology, process and products (Fig. 2). Innovation in each of these areas reported in the last decade will be discussed here.

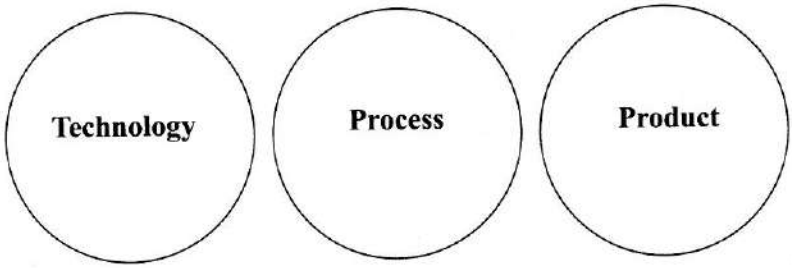

Fig.2. Areas of innovation in spinning

TECHNOLOGY

Spinning preparatory

The spinning preparatory relates to all the processes prior to actual spinning operation i.e. opening and cleaning, carding, drawing, combing, roving production etc. In the blow room one finds the multiple licker in type roller for opening and cleaning units with on line adjustment of cleaning efficiency and waste to be one such innovation. This has resulted in shortening of opening and cleaning line and ease of adjustment of the process.

Detection of contaminants especially white or transparent pieces goes a long way in improving the quality of yarns and fabrics. Ultraviolet radiation is being used for the detection of foreign pieces. The intrinsic florescence of non-coloured particles is exploited for detection and subsequent separation. Loptex uses ultra sound and the intensity of its reflection due to differences in density as a sensor for the separation of polypropylene.

SPINNING

Compact spinning [2,3]

Compact spinning is probably the most significant innovation in the recent past. It is essentially based upon ring spinning technology, is probably one of the most significant innovations in the recent past. The wide spinning triangle in ring spinning (Fig.3) leads to fly liberation and hairiness generation as the edge fibres escape twisting action. Hence suppressing the spinning triangle by pneumatic or mechanical means (Fig.4)will cause most of the fibres emanating from front roller nip to get integrated into the twisted yarn structure.

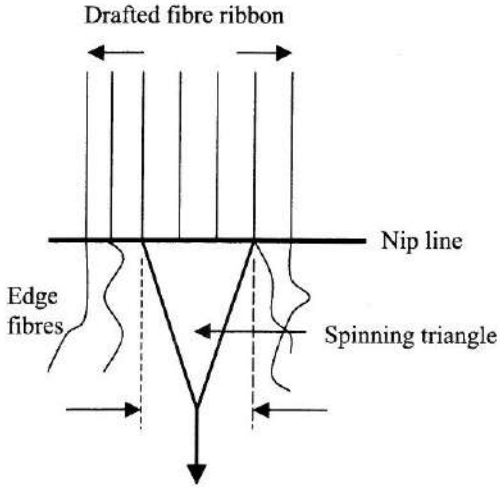

Fig.3. Normal of spinning triangle

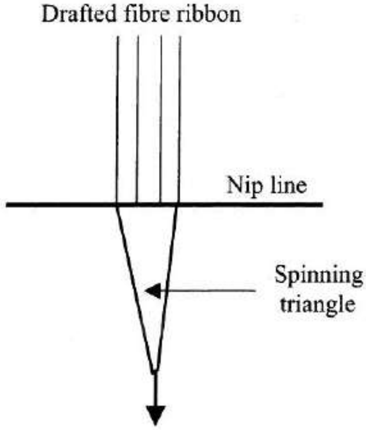

Fig.4 Suppressed spinning triangle

The pneumatic compaction is practiced by Rieter (Com4 system), Zinser (CompACT system), Suessen (Elite system, Fig 5) and Marzoli (Olfil system). LMW (Lakshmi Machine works) has incorporated magnetic compaction where a small condenser placed between a pair of top front rollers is held against the bottom front roller by magnetic means. The drafted material while passing through the compacting zone gets condensed. The condenser needs to be changed depending upon the yarn count. In Table1 a list few manufacturers and their method of compaction of spinning triangle is given.

Table1: Method of compaction by different manufacturers

S. No.	Manufacturer	Trade name	Compacted by	Method of compaction
1	Rieter	Com4 Spin	Air suction through bottom front roller	By perforated bottom front roller and two top rollers
2	Zinser	CompACT Air-com-tex700	Air suction through perforated apron	By perforated apron rotating around top front roller
3	Suessen	Elite	Air suction through perforated apron	By special lattice perforated apron rotating around slotted air suction tube
5	Officeine Gaudino	MCS system	Mechanical compacting	False twist generated by additional smooth front roller and angled top roller running at slower speed than usual front rollers
6	LMW	Rotorcraft	Magnetic compacting	Condenser held against bottom front drafting roller by magnet

The suppression of spinning triangle leading to better integration of constituent fibres (Fig.6) results in following advantages: improvement in yarn quality with respect to strength & elongation, abrasion resistance, imperfection.

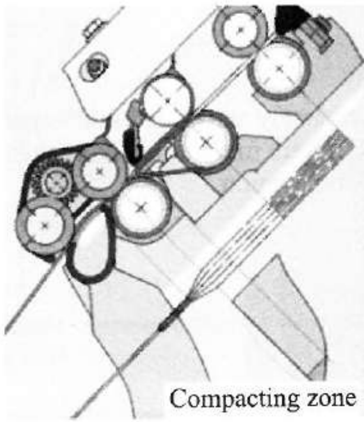

Fig 5. Elite compact spinning

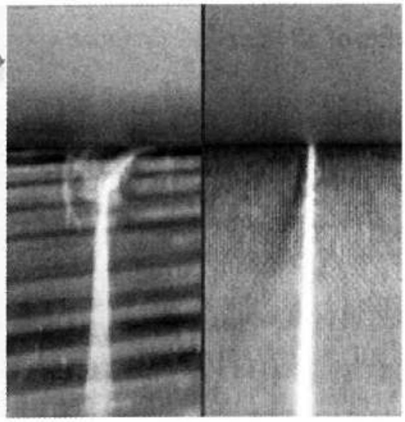

Fig 6 Ring spinning triangle (left) & compact spinning triangle (right) (courtesy Suessen)

But the most significant improvement is observed in hairiness especially long hairs (>3 mm). The improvement in properties is more, the shorter the fibres or coarser the count. There is also improvement in process performance such as less end breaks in spinning (reduction by 50 %), reduced size consumption (by 30%),

less waste accumulation below loom, less fly liberation in weaving & knitting, and better running performance in weaving and knitting. The product quality improves with respect to more uniform appearance, improved lusture, reduced pilling tendency, high breaking and tearing strength and possibilities to impart non ironing ammonia finish as strength reduction due to finish gets compensated by increased fabric strength.

The shortcomings are reduction in spinning speed due to inadequate development of fibre lubricating film on the traveler, lower degree of fabric coverage due to reduced yarn diameter, easy detection of faults (thick places, neps etc.) and slow wicking of water.

Spun - plied technology

It is based on the principle of Siro-spinning technology. In Siro spinning two rovings are fed in the same drafting unit and drafted independently. They emerge as separated drafted entity from the front roller and then meet at a point where they are twisted together as separated strand by the twist emanating from ring traveler twisting system. In this spun plied technology (Fig.7), only two rovings are fed to the drafting unit and the drafted rovings are consolidated by pneumatic means in a way similar to compact spinning and twisted together. The brand name of the technology developed by Suessen is known as *EliTwist* process. The advantages are

- Reduction in twisting triangle substantially which a traditional Siro spinning system does not allow
- An excellent suppression of hairs
- benefits of all the plied structure

The two components of the yarn cannot be completely untwisted and separated, what is possible with a conventional two-ply yarn. The yarns are more twist lively than conventional two-ply yarns owing to the additional influence of compaction.

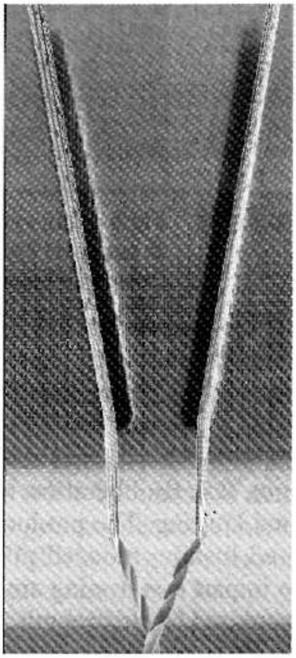

Fig .7 Eli twist process

Solospun technology

Recently Wool Mark company has developed Solospun technology (Fig.8), which suits long staple fibres. It consists of an additional small multi grooved or slotted plastic top roller placed in front of the usual front roller. It separates out the drafted ribbon of fibres into a number of sub-strands (Fig.9). The sub strands converge at varied angles and combine themselves at the apex point of the twist triangle and get consolidated them by the usual twisting action. The twist present in the sub strands in trapping each fibre by the

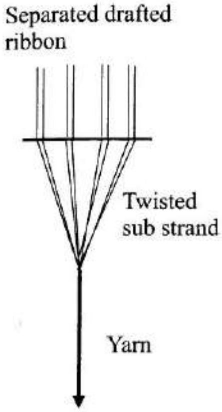

Fig. 9 Schematic representation of spinning zone

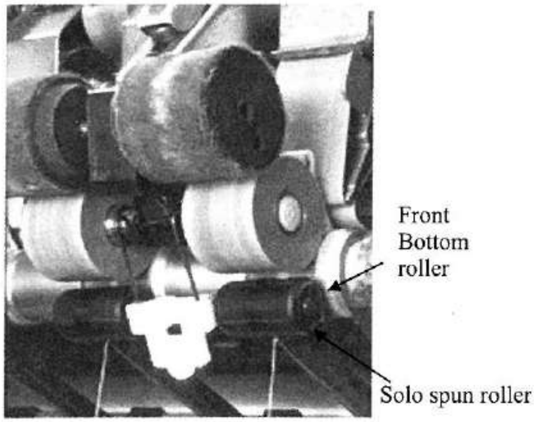

Fig 8 Solo spun Technology

neighbouring strands and by migration within and between strands. The rollers are made from a hard rubberized plastic with anti-static additives to have a low lapping propensity.

The yarns (count range 32Nm to 20Nm) are visibly indistinguishable from a normal singles yarn, and resistant to abrasion to be weavable in the warp.

Murata Vortex spinning [4,5]

In this technology a sliver drafted to a desired yarn is introduced into a nozzle (Fig. 10) .The fibers sucked into the nozzle converge at a pin protruding towards the spindle(Fig. 11). As they converge, the fibers are dragged down into the spindle. At this point, trailing fibers ends are lifted by the high-speed air vortex inside the nozzle chamber such that they separate and swirl around the spindle. As these fibers are dragged again into the spindle, twist is imparted due to their rotation around the spindle. Since the end of the fibers is left completely open, MVS yarn is provided with a true twist structure. The system is suitable for medium to fine count yarn.

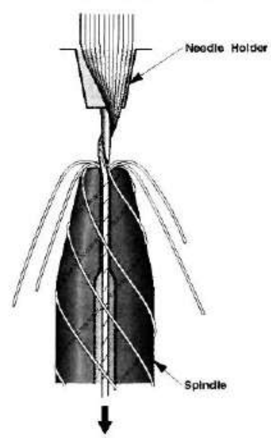

Fig. 11 MVS Spinning principle

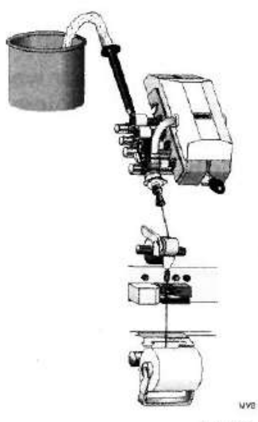

Fig. 10 MVS system

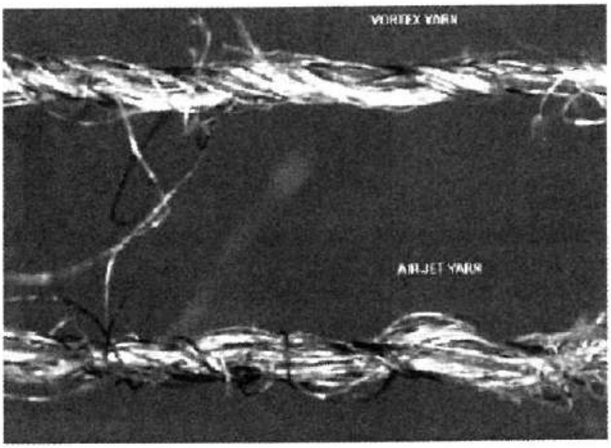

Fig. 12 Vortex and air jet yarns (3)

The yarns have a two part structure a core and a sheath (4). The long fibres converge to the core and the short fibres diverge to the outer layer. The technology is suitable for man-mades and their blends with cotton. Production of 100% cotton yarn may be difficult due to presence of short fibres and trash. The production speed can go up to 400m/min.The tenacity of vortex yarns is usually greater than that of air jet yarn though elongation % is less. The hairiness is less than ring yarn and best suited for medium count from carded cotton as lot of short fibres is eliminated during spinning process.

Process

Adjustment of the process in terms of adjustment of speed of different organs of the machine and other setting related parameters to suit the nature of fibre is usually a cumbersome and lengthy operation. It needs skilled manpower and time. Besides a process needs to be monitored either on an off line or on line basis to ensure consistent yarn quality. Innovation in these areas could be of great help to the industry.

Developments in sensor technology and IT have made process control very effective. Today almost every machine has an on-board microprocessor with bi-directional communication facility. Automatic bale lay down and monitoring of blending lines ensures optimization of raw material and consistent yarn quality. Auto-leveling devices with improved efficiency to control sliver mass variation are common with cards and draw frame. Monitoring of card web and using the information to grind the wire points at the appropriate time assures improved sliver quality. Process monitoring and collection of all production and performance related data, their compilation and presentation in a easily comprehensible manner is common toady.

Continuous monitoring of the degree of whiteness of waste has been used to adjust the separation of opening equipments or mote knife settings in cards to control cleaning.

Individual drives and sensors have made possible self-learning and self-adjusting of drafting process [2]. In Trutzschler draw frame (TD03) the middle roller is driven by a servomotor. Changing middle roller speed alters the drafting force in the break-drafting zone. The drafting force is recorded and the optimum draft i.e. the draft at which the drafting force is maximum, is determined and adjusted automatically on the machine. The roller setting is precisely and reproducibly adjusted obviating the need of skilled manpower.

Products

New yarns using existing technologies are being continuously developed to enhance their functional capabilities and aesthetic appeal. Blending has been the usual route to achieve these capabilities. Complex yarns featuring random slobs, multi-count and multi-twist effects are being produced.

Yarns with unique characteristics such as anti-bacterial, anti-fungal, anti-stress, anti-static and UV-protective are being developed for athletic wear.

For hosiery there are ultra-soft ring-spun yarns using micro Modal®/cotton or micro Modal/micro acrylic. A tri-blend developed for bed linens containing micro-polyester/micro Modal/cotton has twice the absorbency of cotton[6].

Unusual blend such as wool blended with trilobal nylon or with steel for a glittering effect have been developed. Yarns spun from 75% wool with 25% steel gives a wrinkled effect. Yarn containing blends of four components acrylic/wool/nylon /lycra (elastic material) are used to knit sweater. Fine wool- micro denier polyester, silk- cotton, fine mohair twisted with tussah silk, filament viscose or linen is some of the interesting blended yarn. Polyvinyl alcohol (PVA)based yarns which dissolves in hot water are developed to produce hollow bulky effect. Polypropylene blended with wool and hollow nylon produces light yarn.

Small amounts of aluminum or carbon are mixed with cashmere to produce antistatic yarns. New fibres like Coolmax mixed with Lycra for recovery, results in excellent techno yarn. Along with micro-fibers, metallic, stretch and easy care, new yarns were shown that are retro-reflective, dissolve in water or are made from paper.

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Emerging Trends In New Generation Fibres

– RN KANUNGO

A new wave of 'Technical Fibre Innovation' is growing among the fibre companies, worldwide, to produce the so called 'New Generation Fibres' which primarily satisfy consumer needs for 'Natural' materials and at the same time addressing Performance and Environmental concerns.

Attempts to make these new man-made fibres to be more natural, have led, to more intensive research in fibre manufacturing towards mimicking the properties of natural fibres, for various fabric end uses such as Apparel wear, Sports and Active wear, Home furnishing etc. Besides, certain High-tech synthetic fibres have been put into specific functional end uses such as in Technical Textiles, Smart and Intelligent textiles. These research efforts have resulted in having today, a wide array of natural man mades and synthetic 'Specialty fibres' available in the market,which have created a significant impact in the fashion trends for the consumer.

In view of the above developments, the present paper attempts to project a comprehensive view of the new generation fibres in terms of their classification, global production and their share vis-à-vis traditional, natural and synthetic fibres, special attributes, application areas, the effect and behaviour in specific textile end products as demanded by today's emerging fashion trend and continued technical innovation.

In textile products, as a starting material 'Fibre' forms the basic foundation. Fibre scientists along with the Textile technologists and Engineers subsequently help in building the textile structure in form of yarns and fabrics, around which the textile designers in particular, with their techno creative skills offer the consumers with the desired products in varied colours, textures, weaves and endless designs to accommodate the modern life styles of the present generation.

The apparel manufacturers, technologists and the fashion designers are more focussed today in the finishing job of converting the various textile fabrics into suitable garments, clothings and made-ups. Fashion designers around the world with their innovative ideas play with the ongoing newly developed fibre and yarn attributes of the 21st century and in fact, dictate the seasonal colour and fashion trends for innovative products to suit the volatile demands of consumer, fashion and taste and also respond to the changing moods of the domestic and international markets.

Evolution and Classification of fibres

Till the beginning of the 20^{th} century, i.e. around 1900, all fibres were 'Natural' such as Cotton, Wool, Silk, Linen and Jute etc., generally available from plants or from animal origin. Almost around the same time during 1891 - 92 the first man-made 'Artificial Silk' - Viscose Rayon was discovered. For the first time, mankind succeeded in producing fibres from a viscous liquid somewhat similar to what silk worms do processed from wood pulp which contains 'Cellulose' the natural polymer present in the basic raw material component of the Cotton fibre. Thus, the early regenerated natural man-made fibres were born which also included two more important fibres in the same Viscose family namely Cuprammonium Rayon and Cellulose Acetate developed during the same period. These were classified as Man-made Regenerated fibres and also known as Man-made cellulosics because of their cellulosic origin.

Almost half-a-century later in 1938, the first synthetic Polyamide fibre 'Nylon' was developed by DuPont followed by the development of Polyester fibre The King of Synthetics in mid 50's. Synthetic fibres, unlike the regenerated cellulosics, were made not from some original natural fibrous material as wood pulp but by synthesis of simple chemicals, derived from the petrochemical sources, which were built up to give a synthetic fibrous material. Thus, a distinct class of man-made fibres for textile use was evolved and was classified as 'Synthetic fibres' or 'Chemical fibres'.

Besides, these two major fibres i.e. Polyamide and Polyester, most of the other notable synthetic fibres such as Acrylic PP (Polypropylene), PVA (Polyvinyl Alcohol), Teflon, Lycra etc. used for various textile applications have been developed during the period 1950-60's.

Subsequently, with the continued intensive research efforts in man made fibres in the last fifty years, a host of new improved form of man made cellulosic fibres namely, Polynosics, Lyocell, Tencel, Modal and other HWM rayons etc. have arrived including man-made protein fibres such as Soybean and the latest PLA (Polylactic Acid) base fibre Ingeo derived from corn starch and some other new fibres of wood and bast fibre origin such as Lenpur, Bamboo and Paper fibres. Many other synthetic fibres and filaments particularly with Polyester and Polyamide bases, have also been developed during the last decade in fabric concepts such as Coolmax, Thermolite, Tactel etc. to suit the functional and aesthetic needs of the present generation.

A comprehensive general classification of textile fibres, is shown in Table-1, which broadly classifies fibres into the following three main categories;

(a) Natural fibres
(b) Man made Regenerated fibres or Natural Man-made fibres.
(c) Man made Synthetic fibres or Chemical fibres.

Table I General Classification Of Textile Fibres

Textile fibres are broadly classified into three major categories. Examples of such fibres in each category has been shown alongside.

1.	Natural Fibres	Cotton, Wool, Silk, Jute, Flax (Linen) etc.	
2. (a)	Man made Regnerated Fibres or Natural man made fibre.	Viscose, Cupra, Acetate etc.	
(b)	New Generation MMRF's	Polynosics, Modal, Tencel, Lyocel, Lenpur, Ingeo(PLA), Soybean etc.	
3. (a)	Man made Synthetic or Chemical fibres	Polyesters,Polyamides(Nylons), Acrylics, Modacrylics etc.	
(b)	Other man made fibres of New Generation	Polyester and Polyamide Micro filaments	Tactel, Meryl, Sensil etc.
		Polyproylene	PP staple fibres and filaments
		Polyvinyal Alchohol(PVA)	Vinylon, Kuralon
		Polyurethanes	Spandex,Lycra,Elastane etc.
		Aramid fibre	Kevlar
		PTFE	Teflon
		Mettalic	Lurex, Kyototex
	Comfort Stretch fibres	DOW-XLA	Lastol (DOW-Fiber Solutions)
		P.B.T.	Polybutylene,Terepthalate-Lestin, Elite
		PTT	Polytrimethylente Terepthalate, Corterra
	Functional Polyester and Polyamide	Coolmax, Thermolite,Cool labo etc.	
	Antimicrobial Fibres	Amicor, Meryl, Skinlife, Silfresh, Trevira, Silvertex etc.	
	Antielectro Magnetic and Antistatic Fibres.	R-stat, Epitropic fibres etc.	

NEW GENERATION FIBRES

Since almost last four decades i.e. from 1960's continuous research efforts world wide are being undertaken by the fibre manufacturers to produce man made fibres which could provide certain cotton like functional and aesthetic properties to the fabrics of the present day fashion conscious consumers. As a result, a new wave of 'Technical fibre innovation' has been growing among the fibre companies[1], globally, to manufacture 'New Generation' fibres which not only helps them in higher cost economy, to carve out strategies for their survival but also to satisfy consumer needs for 'Natural' materials and at the same time addressing performance and environmental concerns.

Coincidentally, a recent world bank study[2] also suggests that the strong average yearly growth rate of 3.5% in world economy during the last forty years (1960-2000) in addition to the population growth (doubling from 3.04 billion to 6.08 billion during the same period) is primarily attributable to two major factors i.e. (1) Technical Innovation and (2) Globalisation of Markets. The industry also continues to benefit from a stream of technical 'New innovative fibres', many of which are aimed at meeting future growth in fibre demand by 'Manufacturing' fibres rather than 'Growing' them, and yet satisfying consumer needs for 'Natural' materials at the same time.

Attempts to make these new man made fibres to be more natural, have led, for example, to more and more intensive research in fibre manufacturing towards mimicking the properties of Natural fibres, by way of polymeric and fibre cross-sectional changes, addition of organic additives into the polymer etc. for various fabric end uses such as Apparel wear, Sports and Active wear, Home furnishing etc. Besides, certain high-tech fibres of synthetic origin have been put into specific functional end uses such as in Technical Textiles, Smart and Intelligent textiles[3]. These research efforts have not only resulted in having, today, a wide array of new generation man made regenerated and synthetic specialty fibres available in the market, but also has created a significant impact in the fashion trends for the consumer.

Particularly, the new man-made cellulosics fibres such as Polynosics, Lyocell, Tencel, Modal and other HWM rayons etc. have been able to offer the consumer all the much needed aesthetics like softer feel, pleasant handle, silky luster etc., because of their cellulosic origin and similarity and nearness in fibre properties to cotton.

Also, a new range of Polyester and Polyamide fibres and micro filaments such as Coolmax, Thermolite and Tactel family of fibres etc. have been specifically engineered by way of polymeric and fibre cross sectional changes in order to impart certain tailor made functional properties such as fabric breathability, thermal body regulation controls and cotton like aesthetics to such fibres for wide variety of textile applications in woven as well as in knits.

A list of currently available new generation fibres has also been shown in Table-1. They are generally classified under the two categories (1) Man-made regenerated fibres or Natural Man-made fibres and (2) Man-made fibres of New generation, other than traditional synthetics such as Polyesters, Nylons, Acrylics etc.

Regenerated Man-made or Natural Man-made fibres

This class of New generation fibres have been specifically engineered and developed with a view to making man made fibres look more natural, feel natural and imparting more cotton like breathable and other aesthetic properties to the fabrics as desired by the present day consumers.

In fabrics, these fibres achieve the balanced properties of performance characteristics of synthetic fibres such as strength, durability easy care, elastic recovery etc. with the aesthetic characteristics of natural fibres such as cotton and silk for breathability, superior feel, silky lustre, pleasant hand and drapability etc. In effect, these class of new fibres offer the consumers,

Table II - New Generation Fibres And Fil Yarns

A. REGENERATED MAN-MADE CELLULOSICS AND PROTEINS

a) TENCEL from Acordis Fibres Ltd., U.K.
b) LYOCELL & MODAL from Lenzing Fibres, Austria
c) POLYNOSICS,TUFCEL & JUNLON Fibres from Japan
d) LENPUR (wood fibre) from Texinpro, Italy
e) PLA Natureworks _ INGEO from Cargill DOW LLC
f) SOYBEAN from Swicofil, Switzerland.

B. MAN-MADE SYNTHETIC FIBRES AND FIL YARNS

a) POLYESTER FIBRE BASE-COOLMAX, THERMOLITE from DuPont and Other Manufacturers
b) POLYESTER MICROFILAMENTS from various manufacturers from Taiwan (Korea), Indonesia, Malaysia etc.
c) POLYAMIDE FILAMENTS TACTEL and CORDURA from DuPont, MERYL from Nylstar, Italy, SENSIL from Nilit, Israel.
d) POLYVINYL ALCOHOL PVA fibre VINYLON & KURALON from Japan.
e) ACRYLIC FIBRE BASE COOL LABO from Toray of Japan.
f) POLYPROPYLENE FIBRES ASOTA F15 from Asota GmbH, Austria.
g) ARAMID FIBRES KEVLAR from DuPont.

C. STRETCH YARN

a) BARE STRETCH YARNS LYCRA from DuPont and other ELASTANE yarns and TYPE S-45 and TYPE S-72 from Radici Spandex
b) COMFORT STRETCH YARNS:
   - XLA FIBRE from DOW Fibre Solutions, Switzerland
   - PBT-Pobutylene Terepthalate - ELITE from Nylstar, Italy. LESTIN from Setilla, Switzerland.
   - PTT-Polytrimethylene Terepthalate CORTERRA from Shell Chemicals, T-400 from DuPont.

D. METALLIC YARN

- LUREX from Lurex Co. Ltd., U.K.
- KYOTOTEX from Kyowa Ltd. Japan

E. OTHER SPECIALITY AND FABRES YARNS

a) Antimicrobial Fibre

ACRYLIC BASE:
- AMICOR from ACORDIS

POLYESTER BASE :
- ATB 100 from Kolon, Korea
- MAGIC SILVER from Hyosung Corpn., Korea
- MERYL SKINLIFE from Nylstar, Italy.

ACETATE BASE :
- SILFRESH from Novaceta.

a) Anti Electromagnetic and Antistatic R-STAT (Polyester with A9.Steel Component)
b) LCP Fiber VECTRAN from Celanese (Liquid Crystal Polymer Multifilament).

the best of both worlds; by way of balancing the fabric properties of natural fibre at one end and the synthetics at the other.
Since these fibres have been regenerated from improved wood based cellulosic source and other forms of natural resources such as corn, soyabean protein etc., most of these impart 'Naturalness' and 'Softness' and other fabric aesthetics to the final product. As well as trying to make fibres more natural, fibre innovators are also addressing growing public concerns about the environment by making these fibres (a) 'Biodegradable' by manufacturing these from 'Self sustaining renewable source' and (b) 'Ecofriendly' through innovative 'Environment friendly' manufacturing processes from the regenerated sources.

New Generation Man made Synthetic fibres and filament yarns

This class of new generation fibres, unlike the man made cellulosics, are manufactured from polymers similar to that of traditional synthetic fibres such as Polyesters, Polyamide, Acrylics, etc. Most of these base fibres are suitably engineered in terms of (a) fibre cross sectional and (b) polymeric changes during manufacture in order to mimic and impart the desired aesthetics of natural fibres such as comfort, softness, breathability etc. in addition to the inherent high performance characteristics of the synthetics such as high strength, durability, easy care, high modulus etc.

Besides, there have been other new generation fibre developments in synthetics man mades. particularly (a) Micro fibres (b) Elastic and comfort stretch fibres (c) Metallic yarns for decorative and embellishment purposes in fabrics.

Another innovative area of synthetic man made fibre development is in the Antimicrobial [4 5] Antistatic and Anti electro magnetic radiation fibre areas where consumers are becoming increasingly aware of hygiene and of the potentially harmful effects of micro organisms, electrostatic buildup, and electro magnetic radiation in fabrics. In fact, there have been continued rise in demand for such specialty fibres and fabrics in recent years.
In the following Table II are shown, most of the important New generation fibres of natural man-made i.e. regenerated man-made cellulosics, starch and protein fibres as well as the fibres and filaments of new generation synthetics, which are in vogue, today and have been widely acclaimed for their versatile applications in textiles.

Global Fibre Production And Consumption

The Table III [6] shows the total global fibre production for all natural and man made fibres in million tons and the percentage share in production of each class of fibres in relation to the total production.

Table - III - Global Fibre Production (2002)

Fibres	Production In Mn Tons	% Share
NATURAL		
1) Cotton	21.0	34.5
2) Other Natural fibres (Silk, Wool, Jute, Hemp,Ramie etc.)	6.5	10.5
Sub Total:	27.5	45.0
NATURAL MAN-MADE (CELLULOSICS)		
1) Traditional Fibres (Viscose,Cupro,Acetate etc.)	2.5	4.0
2) New Generation Fibres (Tencel, Lyocell, Modal, PLA, Soybean etc.)	0.2	0.3
Sub Total:	2.7	4.3
SYNTHETIC MAN – MADE		
1) Traditional Fibres (Polyester,Polyamide and Polyacrylics) Polyester- 20.9, Polyamide - 3.9, Acrylic - 2.7	27.5	45.0
2) New Generation Fibres (PP, PVA, PTEF, Lycra, DOW-XLA, Other high tech. Fibres)	3.5	5.7
Sub Total:	31.0	50.7
GRAND TOTAL	61..2	100%
WORLD POPULATION (IN BILLIONS)	6.4	
PER CAPITA CONSUMPTION (ALL FIBRES IN KGS.)	9.6	

It could be observed from Table-III that in 2002, the global all fibre production was around 61.2 million tons with the cotton and other natural fibres sharing an output of 27. 5 million tons, constituting 45% of the share. The remaining 33.7 million tons i.e. 55% of the global fibre output is shared by man made fibres (Natural man mades + Synthetic man mades).

Out of the 55% share of the man made fibres, traditional synthetic fibres such as Polyester, Polyamides, Acrylics etc. enjoys the maximum output of 27.5 million tons ie. 45%, the remaining 10% being distributed amongst New generation fibres (Natural cellulosics and proteins + New generation synthetics) and traditional man-made cellulosics such as Viscose, Cupro and Acetate etc.

In the traditional synthetic man made fibre output of 27.5 million tons, Polyester has the maximum out put of 20.9 million tons Nylon (Polyamide) 3.9 and Acrylic 2.7 million tons. Thus, in the overall global fibre scenario, Polyester and cotton share almost equal volume of output i.e. 21 million tons (34.5%) each.

The average growth rate in cotton production in the period 1982-2002(Table IV) [7] has been only 2.2% per year as compared to the growth rate of 7% for man-made (Natural + Synthetic) fibres. Thus man made fibres including the natural man mades will continue to expand their market share at the expense of cotton and other natural fibres, to meet growing demands in apparel and home furnishings as well as a continuing production of synthetics for tufted carpeting technical textiles and other industrial applications.

Global production of New Generation fibres

The combined production of New generation fibres (Natural man-made + Synthetic Man-made) in 2005 would be approximately 4 million tons, out of which the share of Natural Man-made fibres such as Tencel, Lyocell, Modal, PLA, Soybean etc. would be 0.3 million tons (7.5%) as compared to that of synthetic man-made fibres like PP, Lycra and other Elastanes, comfort stretch fibres of DOW-XLA, PBT, PTT, etc. and other high tech. fibres would be 3.7 million tons (92.5%). Thus overall new generation fibres account for approximately 6% of the global production.

Table IV - Global Fibre Production Growth (1982 2002)

Fibre Type	Production In Million Tons(1982)	Production In Million Tons 2002	Growth % In 20 Years	Average Growth %
Cotton	14.5	21.0	+ 44.8	+ 2.2
Other Natural fibres (Silk, Wool. Jute, Flax etc.)	4.0	6.5	+ 38.5	+ 1.9
Man Made fibres (Natural + Synthetic)	14.1	33.7	+ 139.0	+ 7.0
All Global fibres (Cotton + Other natural + Man-made {Natural + Synthetic })	32.6	61.2	+ 87.7	+ 4.4

Cotton vs. New Generation fibres

Initially from the consumer's point of view, cotton had all the necessary advantages of price, comfort and other fabric aesthetics. But with the continued production growth and development of man made fibres in recent years, this advantage of cotton has been somewhat off set. Added to this misery of cotton, and to the advantage of man mades, the world wide production of cotton has also remained stagnant for the last few years and it is very unlikely that this situation will improve any further, which could be clearly observed from the Figs. I. and II.

From both these studies, it has been quite evident that, since the beginning of the 90's man made fibres have been the most important fibre types in terms of production and volume consumption and today, barring silk and wool, whose shares are too meagre to the overall fibre scenario, cotton's share in production as well as in market share in consumption is only around 35-40%; roughly a third of the total global fibre production.

As per the Geerde International's projection, over the next couple of decades cotton production could still grow by at most 10%. In contrast, due to the tremendous development expected in man-made fibres in future years their production would be expected to be around more than 100 million tons in 2040.

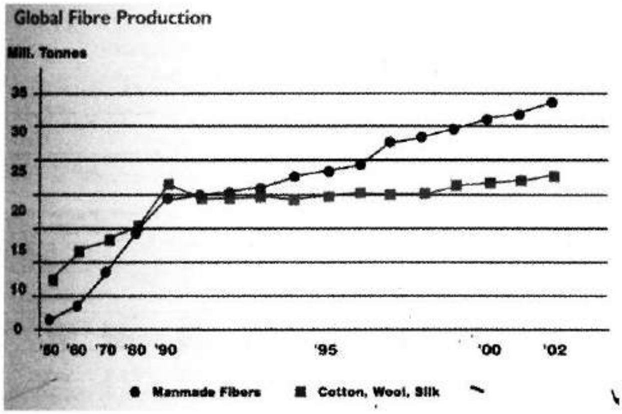

Fig I

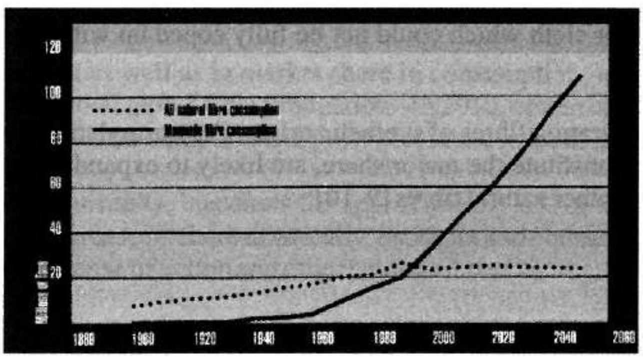

Fig II

The Fig.I [6] indicates the growth in global fibre production from 1950-2002 from the annual study of Saurer '02, and the Fig. II shows a long term volume projection by Geerdes International, USA[8] for all natural fibres consumption against that of all man-made fibres since 1900 to 2040

According to another forecast by the US based International Cotton Advisory Committee (ICAC)[1], during the coming 5 6 years to 2010, the non-cotton consumption will grow more than twice as fast as cotton. So it seems inevitable that demand growth will have to be met predominantly by expanding New generation man made fibre production.

In developing countries like China, India and Pakistan where production and consumption of cotton is dominant,(Fig.III)[2] new generation fibres particularly man-made cellulosics fibres such as Tencel, Lyocell, Modal etc. are likely to replace cotton because of their (a) high wear comfort (b) excellent moisture absorbency and (c) good breathing properties.

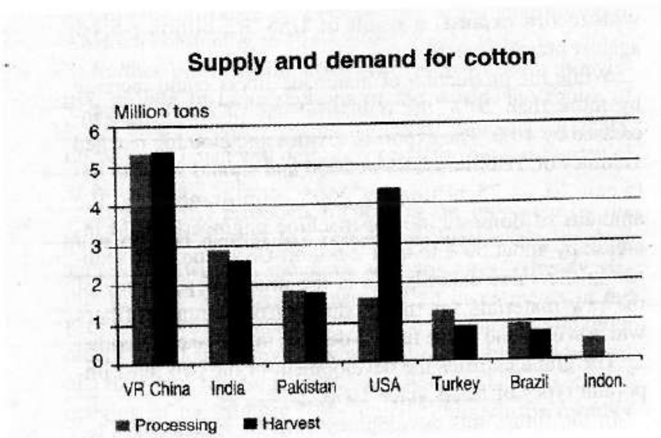

Fig.III

Further, higher life expectancy and high birth rates in developing countries will create additional demands for cloth which could not be fully coped up with the marginal growth in cotton production.

Amongst the new generation fibres of synthetic origin, Polypropylene, Elastanes and Comfort stretch fibres which constitute the major share, are likely to expand their market share at the expense of cotton and other natural fibres [9 10]

FUTURE TRENDS

1) Globally, the demand for new generation fibres will continue to grow due to the growth in world population, continued technical innovation and new application in' Manufacturing' fibre rather than in the area of 'Growing' fibres.
2) Additional demand of fibres due to increased population will be created in growing large scale developing economy countries like China and India.
3) With higher incomes, people will want to have more than just the bare necessity. Fashion will stimulate this growth further.

4) The growing number of consumers in the developing countries will want to enjoy comfort, hence, demanding man made cellulosic fibres for their high wear comfort. Although, Polyester will continue to play a key role in the future new generation fibres, consumers will not want to forego the comfort of Natural man made fibres [11].

5) Future consumers will be more and more aware and conscious in demanding more sustainable environment friendly and fully biodegradable products with natural aesthetics in new generation fibres. This will open up a new trend and opportunity for natural man made cellulosics and protein fibres like Lyocell, Tencel, Modal, Lenpur, PLA (Ingeo), Soybean etc.

6) The textile fibre industries will continue to shift incrementally, to the cheap labour intensive developing areas of Asia, Africa/Middle East and Latin America from the developed countries, in order to capitalise on competitive cost advantage [7].

CONCLUSION

A new wave of 'Technical fibre innovation' is helping fibre companies in higher cost economies to carve out a strategy for survival. The new generation fibres satisfy consumer needs for 'Natural' materials and at the same time, address performance and environmental concerns.

Currently 6.4 billion people consume around 60 billion kg. of textile fibres, per capita consumption being approximately 10 kg. of fibres per year.

Today the mass fibre market is dominated by Polyester and Cotton. These two fibres account for almost 70% of the total global output of fibres.

Cotton's share in production as well as in market share in consumption, today is only around 35%, roughly a third of the total global fibre production. In 2010, cotton is expected to grow at the most 10% while non cotton consumption will grow more than twice as fast as cotton..

The new generation fibre, currently, accounts for approximately 6% of the total global fibre output, and is expected to increase its share drastically, in output and consumption over the next couple of decades, at the expense of cotton and other natural fibres.

New generation man made fibres of synthetic origin such as Polypropylene. Elastanes, Comfort stretch (PBT, PTT, DOW-XLA Conjugate fibres etc.) and other high performance fibres will also continue to expand their market share at the expenses of natural fibres to meet the growing demands in apparel, home furnishings as well as in technical textiles sector. In particular PP will benefit from strong demand as a primary and secondary backing fibre in carpet manufacturing replacing the natural fibre such as Jute and as a face fibre in carpeting instead of Nylon.

New generation man made naturals and high tech. synthetic fibres will continue to provide cost effective solutions to specialised applications in terms of (a) innovations in fibre performance (b) comfort (c) aesthetic characteristics and (d) smart functional textiles.

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The Theoretics And Last Development Of Nomex® Thermal Protective Fiber

ZHU FANGLONG & ZHANG WEIYUAN

Nomex® fibers have been widely used in many fields due to their favorable properties, such as high intensity, corrosion resistance, low expansivity, abrasion-proof, thermal insulation, good resilience, etc. The paper intends to provide a solid overview of the definitions, properties, products and end uses of high temperature resistant fibers-Nomex®.

Protective apparel from asbestos fiber resists intense heat, flame and break open, hazards associated with exposure to melted medal. It is well known that much more exposure to asbestos cause health effects in human tissues, therefore it is demanded that faster, stronger, lighter, safer should be pushed upon today's researchers and manufacturers. Man-made fibers including different kinds of flame resistant fiber such as flame-resistant cellulose fiber [2], acrylic, aramids, PBI, glass fiber, carbon arimid fiber, Teflon's fiber, etc aid enormously in allowing products to meet these challenges.

In general, fire resistant fiber is recognized as a group of fibers whose limit oxygen index is above 25 and that of high fire resistant fiber can reach 31 including natural flame resistant fiber and flame resistant fiber which was added material when processing [2]. Aramids belong to the latter. Nomex® fibers [1] are from the generic fiber group called meta-aramid developed and marketed by Dupont. As an inherently flameproof synthetic textile. The research of Nomex® fiber, begun in the late 1950's, led to subsequent laboratory production and extensive evaluation of fiber originally called HT-1.Adoption of the trademark Nomex® nylon was announced in 1963, when pilot plant facilities commenced operation. By 1967, Nomex® was available commercially. In 1972 the trade name Nomex® aramid was adopted. Nomex® has been woven, knitted, braided, and felted into different apparel fabric to protect against flash fire and electric arc exposure; firefighter garments; fabrics and spun yarns for filtration applications; insutlation in fire resistant protective clothing; rubber reinforcement; and in transportation textiles such as aircraft carpeting in order to meet the varied requirements of industry and firefighting. Another brand name from this fiber group is Conex® [4]. Conex® is a registered trademark name of Aramid, Ltd. while Nomex® is a registered trademark of E.I.Dupont Nemours & Company.

Unlike flame-retardant treated (FRT) materials, Nomex® fibers are inherently flame resistant (FR) [1]: the flame resistance is an inherent property of the polymer chemistry. It will not diminish during the life of the fiber. The fiber's low stiffness and high elongation give it textile-like characteristics, which allow processing on conventional textile equipment.

CHEMICAL STRUCTURE OF NOMEX® FIBER

Aramids [1] are a family of nylons, including Nomex® and Kevlar. Kevlar is a polyamide, in which all the amide groups are separated by para-phenylene groups, that is, the amide groups attach to the phenyl rings opposite to each other, at carbons 1 and 4. Nomex®, on the other hand, has meta-phenylene groups, that is, the amide groups are attached to the phenyl ring at the 1 and 3 positions. Figure 1 shows its molecular structure picture:

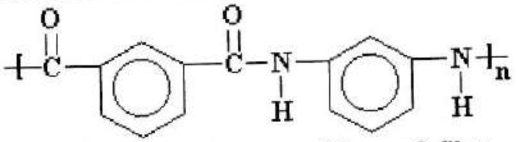

Fig.1 Chemical structure of Nomex® fiber

In Nomex® the aromatic groups are all linked into the backbone chain through the 1 and 3 positions. This is called meta-linkage.

FIBER PROPERTIES

Nomex® fiber, a member of the aramid family of fibers, offers excellent flame resistance, good textile properties, dimensional stability, and resistance to degradation by a wide range of chemicals and industrial solvents [5]. Du Pont Nomex® fiber does not melt and drip, burn or support combustion When exposed to flame, the Nomex® aramid fiber carbonizes and becomes thicker, forming a protective barrier between the heat source and the skin. This protective barrier stays supple until it cools, giving the wearer extra seconds of protection for escape. The polymer from which the Nomex® aramid fiber is spun does not support combustion. The flame resistance is built into the fiber itself; it does not come from a topical chemical treatment. Therefore, the flame resistance of fiber is permanent; no amount of laundering or wear can remove it. Table 1 lists some physical characteristics of Nomex® fiber:

Table 1 Basic Physical Characteristics of Nomex® Fiber

Properties	Filament	Staple fibers
Breaking Tenacity, $Ntex^{-1}$	0.47	4.0
Wetting Tenacity, $Ntex^{-1}$	0.36	?
Elongation, %	22	34
Elongation in Wet Condition, %	16	?
Flexibility Modulus, $Ntex^{-1}$	15.6	70
Shrinkage in Boiling Water, %	<1.5	?
Shrinkage in Dry Air at 265?,%	<1	?
Regain, %	5.5	?
Density, cm^{-1}	1.38	?
Specific Heat, $J(g¡æ)^{-1}$	0.29	?
Cross Section	Dog Bone Shaped	?
VitrificationTemperature,Tg/¡æ	270	?

Nomex® shows essentially no embrittlement or degradation at cryogenic conditions. At room temperature the tensile properties are in the same range as those of nylon and polyester, making it easily processable on standard textile equipment.

Thermal Properties

Nomex® meta-aramid, poly (meta-phenyleneisophthal-amide) is a long chain polyamide in which at least 85% of the amide linkage are attached directly to two aromatic rings. The aromatic rings and the conjugated amide bonds that link them together are particularly strong and resistant to chemical attack. They also provide a high degree of heat resistance to the polymer backbone. As a result, Nomex® does not melt and drip, and merely chars when exposed to high temperatures for prolonged periods. Thus Nomex® fiber does not ignite, melt, or drip in Federal Vertical Flame Tests FSTM5903 and FSTM 5905. And Nomex® 's inherent flame resistance is permanent for the life of the garment. Another, when exposed to flame or high temperature, fabric made of Nomex® fiber do not shrink or embrittle.

Strain-stress on different temperature

Nomex® has good stress-strain properties at temperatures above the melting point of most other synthetic fibers [5]. Increasing temperature reduces the tensile strength, modulus, and break elongation of yarns of Nomex®. Fibers tested after exposure to various temperatures for 5 minutes in dry air give the stress-strain curves shown in Figure 2. The typical stress-strain curve shows that at elevated temperature, Nomex® fiber exhibits a progressive increase in strain with the same load.

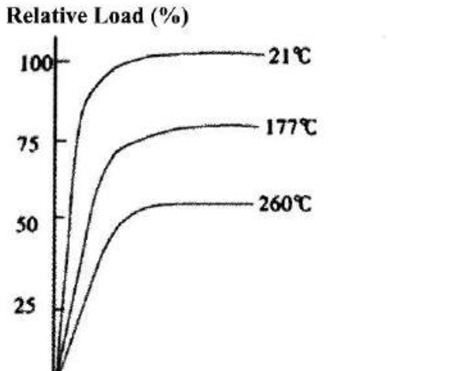

Figure 1 Stress-Strain curves on different temperature

Chemical Resistance

Nomex® fiber exhibits very good resistance to many chemicals. It is highly resistant to most hydrocarbons and organic solvents. Chemical resistance during exposure in use and to chemicals and solvents used in cleaning contributes to the excellent durability and wear life of garments of Nomex®. In addition, the resistance of Nomex® acid solutions is better than that of nylon, but not as good as that of polyester. However, at elevated temperature, its resistance to acid vapors is better than that of polyester. Nomex® shows excellent resistance to alkalis at room temperature, but is degraded by strong alkalis at high temperature. Much more information on the chemical resistance of Nomex III is shown in Table II.

Table 2 Chemical Resistance of Nomex III fabric

Details / Chemical	Concentration %	Temperature %	Time Hr	Effect on Breaking strength
Hydrochloric	10	21	1000	Appreciable
	10	71	10	Appreciable
	37	71	10	Degraded
Hydrofluoric	10	21	100	None
	10	99	10	Moderate
Acetic	5	99	1000	None
	100	21	100	None
	100	99	100	None
Chromic	10	21	1000	None
	10	99	100	Degraded
	30	99	10	Degraded

NOMEX® FIBER PASSES THE TESTS

Results of standard tests show the superior thermal properties and durability of Nomex® fiber over FR cotton in typical protective clothing fabrics [3]. In the vertical flame test, the fabric made with Nomex® has a char length only one-fourth that of the FR cotton fabric. The fabric containing Nomex® fiber has no after-flame even with two 10-second burns, as specified in Federal Vertical Flame Test 5905 [6], and it remains supple after exposure to flame and high temperature.

Garments made with Nomex® fiber are durable. Tensile strength, burst strength, and abrasion tests illustrate their excellent performance in use. In Elmendorf tear tests, tear resistance of the fabric containing Nomex® is 1.5 times higher than that of the competitive FR cotton fabric. Garments of Nomex® fiber have the excellent chemical resistance and electrical resistivity characteristics required for protective clothing used in chemical plants, oil refineries and utility companies. The fabric maintains more than 85% of its original tensile strength even after 10 hours of contact with hydrochloric acid, sodium hydroxide, acetone, or gasoline. Nomex® fiber guards against static build-up in volatile environments.

Along with outstanding protection and durability, the fabric containing Nomex® fiber is comfortable and practical. With a moisture regain of over 8%, the blend fabric will absorb over 130% more perspiration than a typical FR cotton fabric. And garments containing Nomex®

fiber are easily machine-washed and dried. Their resistance to flame and heat exposure, chemical resistance and static dissipative properties are inherent to the fiber and are not affected by laundering.

TYPICAL APPLICATION

Because of its excellent physical and thermal properties, Nomex® brand fiber is used in a wide variety of applications [3], including industrial coated fabrics, ironing or pressing-machine covers, rubber hose reinforcement, felt scrim.

Also because of its unique combination of textile and thermal properties, Nomex fiber is used in a broad range of thermal protective apparel applications wherever the risk of a fire or electric are exposure is present. These include industrial workwear for petroleum, petrochemical and chemical operators, mechanics and electricians, as well as electrical utility employees. Nomex is also used by race car drivers, and their crew, and rocket fuel handles. Further, Nomex® is used when there is an expectation that the individual will be exposed to flames, e.g., in firefighter turnout coats and station wear. Garments of Nomex® may also be used for protection against molten metal splatter under certain circumstances.

Filter bags of Nomex are the industry leader in asphalt manufacturing facilities, as well as a variety of other application. Filter bags of Nomex permit these facilities to operate at higher temperature, which significantly improves capacity, lowers power costs and eliminates condensation.

The superior performance and attractiveness of Nomex® CGF® and Nomex Thermocolor® enable these fibers to be used in a wide variety of applications. They allow creation of beautiful interior textiles including upholstery, floor covering, bulkheads, and wall coverings, to contract furnishings for hotels, offices, auditoriums, hospitals and day care centers.

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21st Century Textiles : The Past Re-invented

— LORNA BIRCHAM

Discussion of the changing role of the textile designer within the context of contemporary attitudes. The paper will be illustrated with examples of current work from textile design graduates and undergraduates from the University of the Arts London. The emphasis of the paper will be the emerging trend for experimentation and invent ion highlighting "hand made" within technology.
Reference to historical precedents of reactions to technological advancements which will underpin the current role of the textile designer. Textile design students are rediscovering traditional skills and finding inspiration in nostalgia. In an attempt to keep them alive and to make them more relevant to current trends in fashion, furnishing and lifestyle they are creating a new niche market. The future of the textile industry may rely on the ability of the designer to keep traditional skills alive. A reaction to digital technology will be a resurgent demand for a more personal, hand-made personal design in which the consumer feels he has bought something unique.

In my role in design education and professional practice, I have been able, over the past twenty years, to mark the changes of attitudes and conventions within the textile industry and the changes of career aspirations from emerging textile designers. This paper and presentation will discuss current trends, ideas and innovations in textiles and shifting attitudes in teaching and learning using illustrations of contemporary work from undergraduate and graduate students from the University of the Arts London. By first briefly referring to historical precedents, I hope to be able to underpin current attitudes of textile designers towards innovation. to highlight the links and possibilities of working within an industrial context and the importance of the need for industry to continue to invest in research and development to keep abreast of emerging innovations. The textile designer today has never been in such an influential position. Their importance has been highlighted in the recent past on the catwalk. The haute couture fashion market has long recognised the need to excite, be controversial, and be individual. Designers such as Christian Lacroix, Hussein Chalyan, Donna Karan, Issey Miyake, invest in unique textile creations commissioning the talents of textile designers.

Exciting developments in textiles embracing new technologies - fibres, chemicals, sensory reactives and electronics are widely promoted, discussed, written about and are the subject of conferences and symposiums. Whilst tempted to refer to them here, they are already well documented.

This paper will concentrate on another emerging trend - the fascination with "the process", which many designers are discovering in their quest for invention. By searching for a way to combine the hand made within latest technology, brand new solutions are evolving. Driven by the need to survive in a very competitive market place new applications have to be found, fitting form to function. Thus the textile designer often finds he is now not only a craftsman, scientist and inventor but also a product designer.

History and Tradition

Innovation is not a new concept. Designers have historically responded to changes resulting from industrial progress and market forces and vice versa. The industrial revolution is recognised as an important time of invention and innovation especially within the textile industry. Until the middle of the eighteenth century textile manufacturing was carried on as a domestic industry but towards the end of the century, with the advent of steam power and the invention of machinery for spinning, weaving and knitting (the fly shuttle by Kay: spinning machinery by Hargreaves, Arkwirght and Compton and the power loom by Cartwright) meant not only social change but a chance for imagination to flourish "…Necessity is the mother of invention"[1] an apt proverb especially in the arena of textile engineering.

However by the turn of the next century there was a huge movement away from mechanised processes. The Arts and Crafts movement epitomised by William Morris and company made a conscious return to the appreciation to the hand made rejecting mass production and the loss of individual identity. This was also probably the most important time for design education. Schools and colleges emerged to train and teach a broad range of craft skills from brick laying to embroidery, from carpentry to drawing.

The remit was not only to promote and preserve craft skills but to offer a vocational training. Text books demonstrating step by step correct procedures enabled teachers to instruct large classes (not unlike modern pedagogic thinking!) It is interesting to note that these instructional books and pamphlets have themselves become a fresh design source inspiring design students to rediscover "lost" skills.

The post war period heralded another wave of design inspiration. Again artists and designers responded to technological advances not only within the textile industry but within diverse fields of science and nature. They were fascinated by new depths of vision enabled by advances in electron microscopy, space technology travel and communication. Iconic designers of the time, textile print designer Lucienne Day, weave designer Marianne Straub, interior designer Terence Conran, strove to initiate new attitudes towards design and industry. Marianne Straub, although trained for industry and was a Fellow of the Society of Industrial Artists, worked for many years encouraging craft skills. She firmly believed that "…the traditional theories of cloth design can constantly be reassessed in the light of a more adventurous attitude towards fabrics and the availability of a changing range of yarns". [2] Through such pioneering thinking, teaching in art and design began to take on a more adventurous approach towards creative design briefs and applications

20-30 years ago strict rules and criteria applied in designing for printed and woven textiles. Repeat, scale, pattern direction and placement, number of colours, cloth structure were taught as technical, invariable standards. Conventional rules applied too for what was appropriate in a furnishing or a fashion context. The standard format of a design was clearly defined and production costs were, of course, paramount.

Career opportunities for designers in industry were limited. Working mainly as studio designers, colourists or selling designs freelance through an agent were the most common ways to earn a living. The designer-maker was a fairly new concept and although the craft fair venue was emerging as a selling opportunity for the crafts person it had limited appeal and status.

There was often resistance from industry to embrace the new, mainly because the new is often so far fetched and impractical and often commercially unviable. Anything too craft based, hand made or experimental was dismissed as impossible to realize industrially. It took a company sure in its own reputation with a sound commercial footing to be able to invest in research and development to move that step ahead. However, in this new century, global competition has resulted in industry being forced to consider their position regarding the increasing consumer demand for customisation and the "human touch". The designer is becoming an influencer innovation is in demand. Graduates are finding a more receptive work place for real creativity and are experiencing a shift in career expectations and commercial opportunities. It might even be stated that we are in the beginning of another industrial revolution. One led by the textile designer.

CONTEMPORARY ATTITUDES

Design students are now constantly searching for the next "new". They are increasingly more adaptable and flexible and are excited by opportunities to collaborate with other designers and artists, crossing boundaries of design and fine art. They devote time to experimentation, combining ideas and techniques. The advent of new technologies in fibre development and digital reprographics has been rapidly picked up and exploited by students, who often take them to their limits, breaking the rules. Researching and connecting ideas is not only a visual journey but a gathering of technical information and material sourcing beyond the usual routes. With a disregard for convention, an appreciation of tradition and an embracing of new technologies, they are now energetically experimenting. They look in unlikely places to find their materials, from second hand sources such as flea markets and recycling depots to scientific, medical and industrial suppliers. It is perhaps interesting to note that Tech Textil Frankfurt will be now including an apparel section "Une 2005", in response to widening interests.

Students delight in putting the disparate together and lately have revelled in discovering forgotten techniques combining these with the latest technologies. Weave students, working with computer aided jacquard sampling use the tool to echo hand embroidery; printers combine digitally manipulated imagery with traditional silk screen methods and use computer programmes to imitate hand drawn and painterly effects; knitters transfer print yarns to echo resist dye effects; embroiders have become fabric manipulators by exploiting fabric properties. All are interested in cross discipline possibilities.

Old textbooks, diagrams and instruction manuals have become a source of knowledge and inspiration. Domestic sewing and needlecraft skills although no longer taught with such rigor in schools are re- emerging as a source of fascination. Instructions in embroidery, smocking, crochet, hand knitting mending and repair are seen as not only with a nostalgic view but as a chance to learn and continue a tradition.......However, in the hands of todays' textile students, these tradtions are not really safely preserved but are ripe for exploitation and expansion!

Other crafts and skills are being re- discovered and are re-surfacing in a textile context. Paper crafts - for example quilling, in which cross-sectioned paper spirals are glued to a surface for decoration, take on a new dimension when applied with textiles. If layers of textured fabrics are rolled and cut into cross sections to reveal multicolour depths they become exciting placements, borders and details; Japanese origami paper folding offers the chance to experiment with plane, colour and form, especially effective when paper is replaced with thermoplastic synthetics, the results suggesting new fashion and interior applications; paper engineering tricks used in book and greeting card design suggest imaginative pop-up variations to a pleated skirt or window blind; traditional woodworking and carpentry techniques such as marquetry and inlay can become fluid drapes when veneers of vellum and cork are inter-cut with silks and velvets to create trompe l'oiel theatrical effects; wood surface decorations such as piercing and hot poker work become literally cutting edge effects on cellulosic non-wovens suggesting nouveau lace and filigree; felted fibres can be embossed, laser cut, etched or moulded into functional forms; in fact, each trial or experiment could be immersed in polyurethane, resin or latex. Why not try to rubberize smocked details on those denim jeans?

The studio/workshop has become an environment of experimentation generating an explosion of ideas. The foundation of theory and skill laid in the first stages of design education forms a firm technical basis and a springboard for the juxtaposition of ideas. From what were traditionally two-dimensional decorative surfaces, textiles are now moving into three dimensions with moving animated parts and exciting visual effects.

The current trend is real invention and textiles have become the "buzz word". To own an original textile from a designer "name" now is on a par with investing in art. It offers the chance to demonstrate ones style awareness. The popularity of select design and craft shows such as the Chelsea Crafts Fair is competitive venue for encouraging designer makers to promote and sell. "Over the past 25 years the Chelsea Crafts Fair has presented the work of thousands of talented designer-makers and has become a formidable forum for design-led craft".[3]

The "life-style" phenomenon has also created a huge general public awareness of design matters. Television programmes and magazines devoted to personal and interior make-overs proliferate, encouraging the wish to personalise and customize, The blurring of the boundaries between fashion and interiors has created a loophole for new product focus. The textile need not have a specific function. Just as a "scarf" can accessorize dress so a textile can accessorize a living space. It's purpose simply to compliment, to be admired, to create a focus. Designers now have opportunities for status for collectors.

Industrial Responses

Technological surges have resulted in huge breakthroughs with textile production. Cad Cam Digital processes, computer software, However there has been a new phenomenon reaction to high tech mass production. Note the endless variations the denim fashion industry has used to customize and personalize their products. In fact, at Chelsea, we have had numerous offers from leading names to collaborate on live projects in which students are given free reign to experiment directly onto cloth to develop effects. New ideas are necessary to keep ahead in a very competitive market but is somewhat ironic to see these effects identically replicated in the shops.

Another example of fashion following and recognising the textile designers' role, is a New York company keen to take students for short work experience. Their design studio is equipped with college workshop facilities. The design brief kept open - students are asked just to experiment. It is a way that middle range retail collections can be individualised, again responding to consumer demands

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An impressive delegate at a previous conference hosted by NIFT in 2000, the subject of which was the SMART revolution within textiles, was Yoichi Yanai from Nisshinbo Industries Inc, Japan His company recognizing the popular demand and appreciation of things hand made had invested thousands in developing a commercially spun yarn which imitated the irregularities and slubs of a hand spun cotton. "For a long time, until now, a uniform appearance has been the most important quality in industrial production. Therefore, the idea to produce industrially uneven products with a natural irregularity may be recognized as revolutionary. The importance of a hand-made appearance in industrial products will increase gradually as the tendency to evaluate natural products higher than artificial ones increases". [4] The resulting fabric appeared to have a hand made human touch quality much admired and valued.

The couture end of the industry has long recognized the niche market for the hand made speciality product. The most cited example is, of course, Issey Miyake, who developed an industrial scale method of replicating hand made thermoplastic pleats first experimented with in the studio. The Swiss textile company, Jakob Schlaepfer is renowned for developing commercial processes to produce experimental prototypes developed in their design studio. The recent collections from Christian Lacroix, John Galliano and Chloe have all included the handmade detail using fabrics by Schlaepfer and I must also state, from recent Chelsea textile graduates.

Textile designers are inventors - the process is their way forward. Students are gaining recognition for their expertise. If industry is not able to develop the ideas further, then the designer will often take the initiative for limited edition production. In fact limited editions are the added value that often sets a product apart. Customizing and hand finishing to add the individual detail is a viable solution to satisfy a demanding market.

CONCLUSION

We are in the midst of another industrial revolution heralded by the digital age. Exciting new technologies are developed daily. Speed of production, shorter response and product delivery times, increased global competition will have an impact on the changing role of the textile industry. However, the predicted reaction to these advances will be a re-evaluation of aesthetic values. Whist the new generation of designers will be quick to embrace new developments, they will also be forced to re-evaluate their position as a designer. An appreciation of heritage and the expertise of the artisan will take on a new importance and future textiles will not just be an homage to tradition, they will be the result imaginative viewpoints, juxtapositions of ideas and, lateral thinking. Careful informed decisions in the choice of materials and awareness of the impact of the process are considerations facing all. Not only from an environmental viewpoint but from a sheer need to survive. In the UK alone approximately 1000 textile design graduates enter the employment market each year. Those equipped with the ability to think laterally, solve problems and to process material, colour and finish for a viable market context will be the survivors. Industry too must also evaluate their position - quickness of production is not always the best profit solution. As the consumer continues to be more discerning and demanding of a more individual product, industry may wish to consider the value of investing in the small. It's all in the detail.

ACKNOWLEDGEMENTS

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Textile Environment: 21st Century Fabric Design

KAY POLITOWICZ

In the 21st century environment textile design and production is a meeting point for architecture, interiors, lighting and decoration not to mention fashion. The reality of textiles in today's society encompasses all of our lives from cloth to grand architectural statements. The future is 'now' - an integration of all disciplines. Architects work with engineers, who develop new techniques. New techniques are an open book to all creative processes. 'Now' is also a time to investigate the cross-design process. At a time when the world is accessible to everyone through the internet, information technology is the 'now'. All processes are available to investigate. How do we, as designers, assimilate and contribute positively in this changing world?

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A series of examples are identified, in which the combinations of existing and emerging technologies are developed into new structures. Textile designers and artists employing ideas and techniques from new technologies are a barometer for change. They produce objects of desire and therefore are critical in changing patterns of consumption in the long term In this study I am identifying a group of designers and academics that are collaborating with scientists to produce portable, flexible environments. It represents the first stage of an ongoing project which develops the potential for an economical, industrial membrane to be transformed through a variety of processes into a vehicle for colour, pattern and light.

The future can be an integration of the virtual, technological and handmade. The definition of a straight line is the shortest distance between two points. Design is not a straight line. I suggest that as designers, we travel forward in a series of circular movements, continuously turning to reflect on progress - so that the progress of design is best described as a flexible chain. Our job is to recognise where we are in the chain and straighten it a little, now. The textile industry is more than usually affected by the contribution of freelance designers and artists who are often the catalyst for international production so it is particularly valuable that all designers actively promote positive changes.

This paper outlines the position of textile designers in relation to the changing role of fabrics as they are being increasingly used in the area between interiors and architecture. Each decade can be said to be identified by a particular material which characterises the look and ideology. In the 1970's it was plastic, in the 1980's postmodernism and MDF (Medium Density Fibreboard). In the 1990's it was glass and a return to modernist thinking. In the 2000's it is sustainability and the use of membranes. They can be made of a variety of materials but usually coated or impregnated with plastic. They can cover MDF and transform it. They can be laminated in glass or be self-supporting and replace it. They can also perform a traditional role in the most modern of interiors and decorate it. In all, they form a bridge between our current unsustainable environment and one that can lead to sustainability and a virtual reality future.

'Now', however is in its infancy. We are trying to balance conflicting ideas where tradition and a fast moving, developing technology, economics, politics and sustainability may be at odds. Oil is still considered 'cheap' and water 'plentiful'. We can learn and develop our concepts from these conflicts. We need to design and engineer better value.

ARCHITECTURAL DEVELOPMENTS

' We put up too many buildings. We squander space, land, mass and energy. We still build the unnatural buildings of past epochs. Our times demand lighter, more energy saving, more mobile and more adaptable (solutions) in short more natural buildings, without disregarding the demands for safety and security' Frei Otto.

Inflatables Before World War II inflatable technology had been focused on becoming airborne but the properties proved useful on the ground as a practical way of producing space-saving devices. The materials were combinations of latex and canvas. The Dunlop Company was responsible for much of the latex technology development.

Since Walter Bird of Cornell Aeronautic Laboratories (CAL) produced in World War II the first inflatable shelter a 'Radome' to house radar antennae, which was a temporary structure. In the 1950's the 'air house' was already explored by Frank Lloyd Wright. This became a familiar concept to architects by 1967 when 'la maison pneumatique' was proposed by Jean Aubert for the Paris Biennale. A rash of proposals followed by the French Utopie Architects. Seen as 'against architecture' and 'critical of architecture'. It was a challenge to the weight, permanence, expense and immobility of traditional architecture but had a highly political agenda which ultimately lost its direction and therefore support.The interest in inflatable reached its peak in 1968 with the 'structures gonflables' exhibition proposed for Osaka's World Fair (1970)In historical perspective it is possible to propose that inflatable objects have a symbolic function in Utopian narratives and revolutionary movements.(Dessauce 1998)

I believe that we are at such a moment again now. The technology revolution makes it possible to propose new structures which are viable. The difference is that today there is a different outlook and focus. Inflatables of the 1960's were about escape and Utopian vision whereas the experience of the last 40 years has been to ground them in reality. Inflatable products have prioritised safety: car airbags, life rafts, swimming aids and comfort: cushions, mattresses and bouncy castles. As far as buildings were concerned inflated dome structures of the 1960's and earlier were often pneumatic calamities partly because there was no way of testing a structure without building it. (Quarmby 1974)

Concentration of stresses, air pressure etc., as well as the character of the fabric itself we are now able to be routinely tested in virtual experiments. (Topham.1988).

Inflatable structures of today, by contrast, have the benefit of newly developed membranes to make them viable. Two notable examples using fluoresin ETFE (Ethylene Tetra Fluoro Ethylene Co-polymer) are:

1. The Eden Project, Cornwall, England. 2001 (Architects Nick Grimshaw + Partners) This project houses over 100,000 plants from many climatic zones of the world in five giant conservatories. The structure integrates a lightweight aluminium system with inflated ETFE foil cushions, forming the shape. The transparent, recyclable 3-layer foil is not degraded by sunlight, is self-cleaning as it is anti-static and inflated with air to insulate the interior. The potentials of the skin are infinite. Laminated membranes can be used for additional functions eg. Colour and pattern on the surface and coloured gases in the cushions.

2. Allianz-Arena, Munich, Germany - 2003-5 (Architects Herzog de Meuron). This sports stadium, to be completed in May 2005, will host the opening match of the Soccer World Cup 2006. The side walls and roof are curved. The transparent section transmits light allowing the grass pitch to grow, whilst the translucent sidewalls can double as monitor screens. This foil, developed especially for the stadium by Asahi Glass, Tokyo is a unique progression in foil technology.

TENSILE STRUCTURES

This is an ancient building form. Throughout history, tents have been used in a variety of environmental and geographical locations. Today they are used in mainstream architectural contexts, particularly in exhibitions, to partition space in interiors and in info-tech applications. An endless range of forms for the membrane structure can be modelled on computer in 3-dimensions, presented in 'virtual installation' form on the specific site and actually installed more readily than other materials. Frei Otto is the seminal figure in modern tensile architecture. His study of natural structures: bubbles, crystals, plants and spiders webs were models for efficient development. His stadium roof for the 1972 Munich Olympics has been cited as one of the great achievements of the 20th century.

New fabrics: primarily nylon, pvc, polyester, polyurethane and fibreglass have been developed to have high strength, longer life spans and high elasticity. The fabrics are composites of woven substrates fibre protected by an applied coating. The woven substrate provides the basic tensile strength of the material and its resistance to tear. The finish seals the fabric against weather and dirt, provides resistance to ultraviolet light, functions as a medium for joining panels and in some cases incorporates fire-resistant chemicals. Fabric manufacturers report that architectural fabrics can be manufactured to vary in translucency from 1% to 80% and in thermal resistance from a single pane of glass to that of a conventionally insulated structure whilst maintaining good levels of daylight. It can also be a light reflector adding to an urban night environment.

Montreal's Olympic Stadium, Canada 1976 (Architects Les Consultants du Stade de Montreal) This example serves to identify what has been learned in the application of fabric to structure. This building was designated and constructed without the use of computer modelling and fabric performance. This stadium, partly completed before the opening of the games in Montreal 1976 had structural problems stemming mainly from the retractable roof system and its mast. The introduction of 60,696 square feet of Kevlar fabric as a tensile roof proved unsuccessful and was replaced in 1996 with non-retractable Teflon coated, fibreglass fabric. The development moves forward.

Georgia Dome, Atlanta U.S.A. 1992 (Architects Weidlinger Associates) This largest cable-supported roof in the world. It is made of Teflon-coated fibreglass, covers more that 395,000 square feet and weighs just 68 pounds. It represents a fundamental engineering breakthrough dubbed 'tensegrity'. It is a complex sequence of triangles of fabric attached to posts by pre-stretched cables. The cable roof is secured to a reinforced concrete ring along the perimeter, resting on Teflon pads, allowing it to flex in high winds. Another engineering breakthrough.

Burj Al Arab (Arabian Tower) Dubai UAE (Architects W.S.Atkins & Ptnrs) The construction, on an island of sand has to withstand storm force winds and radiant heat. A fixed sail shaped fabric façade performs many ecological functions, night and day. It is one of the world's tallest buildings at 332m in which the Teflon sail is attached to an aluminium frame with 3M adhesive tape.

THE INTELLIGENT WALL

Just as nature is' intelligent' in its seasonal changes, architecture seeks 'intelligent' responsive materials to fulfil functions, which are integrated into the material, representing form and function.

The foil or membrane system can be manipulated to change its molecular structure via light or electricity or by integration of secondary micro systems. These secondary films/coatings offer a great economic potential to what in the past seemed non-viable. They can, in some cases, create sustainable environments offering the textile industry a way forward to the 'now'. A few notable examples of coatings, films and meshes follow:

Photo Voltaic cells (PV) - crystalline structures are integrated into skins to absorb solar power and transfer it to energy. Often called solar cells, they can be laminated into glass and plastics or sometimes sewn /bonded to a cushioned vinyl and become a solar battery charger.

Poly Vinyl Butyral (PVB) - These are coatings which can simply be laminated into transparent materials or screen-printed into transparency/translucency and colour. When connected to an electronic charge they are able to change from transparent to opaque immediately by changing their molecular structure. Daewoo Electronics originally devised the concept for use in microwave ovens. This is exciting, if currently expensive.

Dichroic coatings - These are solar-sensitive colour filter coatings in glass potentially achieving many decorative effects. They can be reflective and protect against heat gain from solar energy, so being available to manipulate the potentially environmentally positive conditions in a building in respect to the context.

Polymer organic LEDs - They consist of a thin film of a polymer sandwiched between two electrodes, usually built on glass or plastic which promise a paper thin, roll-up electro luminescent wall covering that is self illuminating. Using ink jet printing or spin coating, these OLEDs offer significant advantages over other materials in their decorative and communication potential, poised to transform our buildings and products.

Metal meshes - Woven stainless steel meshes form a group of woven wire fabrics. They are often used as partition walls, suspended ceilings, facades, claddings, windbreaks and sunscreens. Electroluminescent wire, normally used in signage is now being incorporated into interior and exterior effects, similar to neon lights. The potential of micro-weaving metals, combined with this system is still in its infancy.

THE ENVIRONMENT

"All technology should be assumed guilty until proved innocent'
David Brower: Friends of the Earth.

Textile designers were largely less well informed of the environmental impact of textile production than manufacturers. They are often one step removed and not involved in the process beyond their understanding and specification. Indeed it may be said that textile designers have been in denial since they initiate the production of more consumption, more waste, more use of resources in their very ideas for products.

Most designers now recognise the challenge and opportunity in designing with an environmental awareness without inhibition. They feel the need to invent the simplest, cheapest, least polluting products whose function is to make individual lives better. The truth is that they can present new environmental solutions.

Some of the technologies involved are based on oil, which is now seen by many as a huge drain on natural resources. Added to this, the emission of toxic gases from plastics from certain processes in production or when burnt and the difficulties of disposal of a no-biodegradable substance makes this building technology seem inappropriate, however economic. Currently, glass in buildings provides an exceptional experience of natural light and space but it can be considered outmoded. The problems associated with it such as, heat gain in the day, the weight, the cost and the need to stop transparency at night. It breaks. It moves. Paxton used it in 1851 - it is ancient. The new developments in transparent foils, already described, address many of the problems but largely continue to rely on oil based products and have the added perception of temporality to add to the equation.

Which materials are 'guilty'? Proving innocence of the use of materials in the eco friendly environment requires complex argument. Without the input of design, technology is neither good nor bad. It is therefore essential that disciplines work together.' Now' is a time to visit the cross-design process. Most initiatives stem from the realisation that something is not quite right. These realisations can become large initiatives or smaller interventions.

'*There are few truths, only relative values*'. This particularly applies to environmental strategies. In materials production, use and disposal there are many relative values to be identified. Whilst the inherent characteristics of each material cannot be compared here, there is often an implication that the most recent technological development must be an improvement on the last.

A CASE STUDY: PARTICLE FABRICS

I would like to propose an example of the work of a group of designers as a small intervention, who experiment using fabric to create light, space and colour. The fabrics perform a very important decorative function whilst altering the space with the patterns of light and shadow that they create when joined into structures.

The exploration of this dual function is the beginning of a creative journey currently undertaken by myself and a group of practitioner-teachers at Chelsea College of Art & Design and London College of Fashion (UAL) London.

We are exploring the potential of fabrics to filter and conduct light and heat, incorporating low-tech treatments to add the quality of the environment. Where possible, we employ physical methods of patterning, rather than chemical, using magnets to build structures and employing techniques which demonstrate environmental principles.

As has already been identified the environmental implications of the choice of materials and processes are important considerations in the development of good design. It is necessary to challenge the myth the 'natural' is more environmentally positive than 'synthetic' in terms of fabric production. It is important to assess the cost of materials in production as well as the cost to the consumer and/or environment to sustain and dispose of them.

The project began with an exhibition funded by the European Union and the London Institute (UAL) entitled 'Shadows of the Infinite'. It took place in Milan, Italy, November 2002 as part of a groundbreaking series of events which sought to bring together artists, designers and physicists across Europe. The motivation for this collaboration was that the arts and sciences have much in common. The questions they ask are similar even if the terms they use are different. Textile designers are influenced by nature in the form of structures and images. Developments in science also provide models which are new and surprising in their beauty, symmetry and asymmetry. Analysis of cell structures, thanks to technology, has thrown up new visual images which are a source of wonder and mystery to the artist and designer. These images occasionally reach the public domain via articles in the public press but are often confined to articles in scientific journals owing to their highly specialist and difficult to understand concept.

An example of this is X-ray crystallography in which the rays are deflected by regularly spaced layers of atoms inside a crystal, just as light is diffracted by a fine grating. The pattern of diffracted rays can be recorded on a photographic plate to calculate the position of each atom. Neutron diffraction provides an experimental method of directly locating atoms. Experiments established in this field since 1997 expand the understanding of the structural universe. In developing designs for this textile installation, we as designers are fascinated and inspired by images from this process.

In this project we have developed designs from neutron diffraction patterns of metals and protein molecules, using non-woven synthetic fabric dyed with indigo held under tension, cut by lasers with light sources to create flexible interior spaces.

The fabric selected was a non-woven polyester and fibreglass membrane produced by Colbond Non-Wovens called Colback used in the flooring, automotive and construction industry. It was introduced to the group by Dr Frances Geesin whose work had already begun to explore the potential of this fabric.

It was found to dye well with indigo and a series of other natural substances such as walnut shells and rust from iron filings. A laser cut interpretation of x-ray diffraction creates patterns with the space by shining light through the fabric and casting shadows. Ultrasonic welding was also used for mark-making and joining the fabric, whilst a heat-gun was used as a drawing tool, melting the fabric in places and revealing the grid beneath.

Metallic foils and shibori dye-techniques were employed to pattern the surface and nylon garment tags borrowed from fashion labelling technology were used as surface embellishment.

The fabric was constructed to enclose and partition the space and to make structures, including hanging lanterns. The entire installation including the lanterns was constructed using powerful magnets, thus making the process of installation relatively simple and non-wasteful.

The continuation of research by members of this group includes additional work on the same fabric, now returned to its 3 metre, 10 metre and 50 metre modules. Using simpler printing techniques from vintage circuit board technology energy is now being introduced into the fabrics themselves to produce light and heat.

Concerns of particular individuals within the group including Frances Geesin's interest in vapour deposition onto the fabric and Becky Earley's exhaust printing techniques will move the into a further stage of production. The potential to use magnets to install the works was further developed for the exhibition 'Artists at Work' New Technology in Textile and Fibre Art at the Museo del Tessuto, Prato, Italy November 2003.

CONCLUSION

In this paper I have traced the past to 'now' in the development of materials which are an important contribution to significant physical elements of our environment. Design relates to all our experience and should be environmentally positive, although not necessarily economic now (energy moguls are difficult to shift) but with careful alliances and sponsorships innovation can change even the most entrenched positions to a more dynamic 'new'.

We extract, remove and destroy natural resources which temporarily seems to solve problems but if this is not sustainable then new problems are created.

The exploration of an integration of industry, technology and design along with the awareness of the use of natural energy solar, wind, water, geo - all can be developed by and with design. Don't be fooled by the past, which has abused nature. Creativity can change the model. Whilst it often seems that new developments come from technology, the textile designer can be the interpreter in contributing creative proposals, which apply the technology in ways that can enhance it. Textile designers can also link the 'now' with earlier techniques and combine them in surprising ways. Inventive proposals, however small, can stimulate new thinking in the direction and quality of progress.

"*You never change things by fighting the existing reality. To change something, build a new model that makes the existing model obsolete.*" Buckminster Fuller.

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Innovation In Textiles: Emerging Indian Design Approaches

VIJAI SINGH KATIYAR

One of the prime objectives of design activity is to strengthen the logical but creative connections. A well-formulated design development strategy frequently becomes the central driving force to provide product definition and satisfy the consumer. Successful design always focuses on suitability of approach to the framework and the product differentiation in the market place. Innovations are generally the product of scenario-oriented thinking. Today, innovation is being used to strengthen a positive image, to establish a product's credibility and to increase the persuasive power of a brand.

The role of textile design has evolved considerably in India in last few decades. Since the wake of globalization and the industry is looking forward to the explorative capabilities and cognitive aspects of design. The new design approaches have increasing focus on the innovation and its process. However, its use as a tool for the business advantage is still limited. Clutter of information, advancement in technology, evolving user needs, etc. are some of the intangible areas that are to be dealt with for any successful innovation. Design seems to help make this task easier. Central part of this thinking is the belief that design being inter-disciplinary in nature can offer a holistic innovation strategy that could be implemented and managed better.

Despite considerable amount of global exposure, technological modernization and diversification, the large sections of Indian textile industry continues to strongly believe in a very structured approach. The structure is more in terms of set patterns of working and not necessarily for building logical competencies for the emerging global challenges. There are areas that still need adequate amount of attention for building cutting edge competencies to withstand global market pressures. And design perhaps tops the list of such an area. Almost every function in the companies so far follows a tradition based approach, only with little modifications, as one of the major parameter for acquiring efficiency of quality and cost. Design, in operational environments, more a less gets guided by the similar approach. Adoption to innovation and systems for encouraging innovative products through design are yet to be put in place.

Inspite of the Indian textile industry being second largest in the world, and accounting for little over 35% of country's total exports, historically the Indian textile industry never had a planned agenda and a unified goal for developing competitiveness matching to the call for innovation. The focus has more been towards developing a cost effective production facility and infrastructure that is driven by the technology and marketing factors. Some very positive efforts did happen in this direction that could help develop India as one of the competitive source for a few product categories. Nevertheless, there has been an increased realization of having been left behind in our ability to cope with diverse demands on design and other product attributes.

Today, the growth of Indian textile industry that was propelled through technology upgradation and expansion of specialized product base, needs both, sustainability as well as a response to contemporary challenge for design innovation. This means that the industry must continuously gear its efforts and methodologies to inculcate the desire to innovate. Textile prices are becoming increasingly competitive worldwide as more and more developing countries enter the global textile trade. To increase, if not to maintain its global market share, the Indian textile industry must look at alternative ways of developing and maintaining the competitiveness with alternative design strategies in place.

Despite the whole world looking at our subcontinent for fresh and innovative design and inspirations that are integral to our traditions, our image as a cheaper conversion site has not changed much. Over the years we could not build a sizable range of products that could fetch higher value. With the present state of things, as a large number of multinationals come into this sector, it may be a tough going ahead. The industry, instead of revamping its strategies it is still groping for means to cut costs further down. With the changing socio- economic scenario of India, it will be extremely difficult to bring down the costs beyond a point.

Analysis of the product range produced by the Indian industry in the last few decades largely reveals that the design quality of the products did not match with the progress we made on technology front. We still need to visit museums in order to see great designs and innovative products. In a country where we have traditional fabrics that excel in all the respects, today with modern technology and `global wisdom' we find that a majority of our manufacturing units are struggling to produce even a regular range of marketable products. During the boom period of Indian textile industry, our companies were rarely concerned to produce something that could be remembered with its innovative value and originality.

The classical strengths of the mechanized industry- that of set production parameters, higher productivity and therefore cheaper cost have already been challenged to the extent that many companies are forced to accept the orders of shorter production runs and with many variables. Flexibility of the technology and the production line has become one of the basic norms for the industry to be able to cater to increasingly fluid customers. The current state of technology provides this flexibility largely through the use of alternative processes or through a combination of alternative technologies.

INNOVATION AS A NEW TREND

Design is undoubtedly emerging as one of the major guiding forces that connects the past and the future seamlessly and at the same time is able to deal with the whole issue and trend of innovation very effectively. It was largely after the mid seventies, when the world markets started taking a different swing that design was given the responsibility to perform a very proactive role. In Indian context, it was a difficult shift that industry is still trying to adapt to smoothly. With the growth of industrial production and the drive for more convenient and inexpensive materials, it is getting more and more difficult to follow the classical approach of design and production and at the same time maintain the profits.

The trend of innovation which developed in the west essentially due to complex shifts in lifestyle and awareness encouraged a constant demand for newness in fashion and textiles with an outrageously different approach to the fabric making itself. And consumers responded to it very favorably. Innovation can again be better understood in terms of upcoming and emerging technologies and geographical patterns of the textile production. Information and knowledge are the key guiding forces for it, for example, the Europe started to focus on areas where they can lead rather than just compete, in order to stay in business. Innovation in design, high tech fibers and fabrics and specialization are the routes Europe is taking today.

In order to be innovative it is important to be design led than just design centric. There are number of ways through which the Indian textile industry is already responding to the need of innovation. The systemic approach to design innovation has attracted considerable amount of business and academic interest as well. On the basis of ongoing elaboration of basic principles, concrete research is also gaining grounds.

One of the major contributors to this trend is a fresh look at the user. The needs of customer and the dynamics of the product attributes have changed considerably. The biggest challenge is developing a product that has innovativeness and something that will inspire the buyer to buy on a basis other than price. However, there are only a few who are able to use innovation as a tool for the business advantage. Clutter of information, advancement in technology, ever evolving user needs, etc. are some of the intangible areas that are to be dealt with frequently. Design in many ways seems to help make this task easier. Central part of this thinking is to accept that design being inter-disciplinary in nature can offer a holistic innovation strategy that could be implemented and managed.

INNOVATION IN TEXTILE DESIGN

Design as such is one discipline where the process of innovation is inherent in its methodology at almost every stage of the approach. But due to the highly complex nature of the processes and methodology and frequently an intangible form of the output makes this mechanism difficult to comprehend. Textile design traditionally was aligned to work within technological constraints and market brief. Due to this, innovation could take place only in the areas where designers could have full control i.e. the process of concept visualization and representation. Decisions like raw material choice, process manipulation, visual merchandising systems, product diversification, etc. were the areas where the designers have had little opportunity to innovate. Though most of the output that is generated even in conventional methods of textile design is very tangible, the utility and implications of the very process of design and whole aspect of its context is seldom understood.

However, things did change with textile design in India due to some opportunities in the social and export sector and a fresh approach to textile design started taking roots. There were some of the landmarks where by the profession was able to take up the responsibility of its actions and apply itself in a very interdisciplinary manner. Today, the process of textile design draws energy from a number of sources. Due to its inherent nature of design which leads to explorations and compels a rather independent search for alternative approaches, it has been able to understand the implications in Indian context. A good amount of learning comes from designer's added interest in techniques, culture and visuality. The very basic elements of textile design i.e. materials, construction, color, form, etc. provide ample scope to the designers for innovations. The need is to perhaps adopt scenario based contextual approach that is strategic.

New Approaches to Innovation in Design

Over the last one decade, the role of textile design has been repositioned; the customer preferences are evolving and the dynamics of the product attributes have changed considerably. The bigger challenge is developing a product that has quality and is innovative. The new design approaches in the textile industry have increased focus on the innovation and its process. There are many ways through which design offers an innovative route. The following approaches are based on the practical experiences that have frequently re-established the role of design further in catalyzing the innovation as well as managing it within the commercial framework.

Developing a Innovation Strategy for Design leadership

Design, today needs to be looked at more than an aesthetic value providing task. Design is increasingly being acknowledged and understood in imparting a strong identity to a brand. In a continually changing world, where the convenience and experience factor are critical for the consumer preferences, the most important qualities a company needs to develop are the ability to fulfill the user needs independently and holistically. A product is distinguished only if its development process looks beyond the present. Satisfying just the immediate need can never create market leadership. Companies that aim to be leader encourage their design team to act, be sensitive to the physical as well as mental needs of users, understand and value diversity, and honor the responsibilities that come with unique cultural contexts.

For creating the design leadership, efforts should be to develop exceptional depth of experiences with the products and processes, including intensive explorations with the smallest possible product specifications, a focus on creative decision making and problem solving, and opportunities for hands on visual research. All this has to be developed as a design strategy that is integrated well with the management vision and business plan. An effective design strategy will include building on the companies existing strengths, distinctive in their product or service attributes and design language, by expanding the focus of design and development. The products that are the outcome of such a process will have a positive impact in the marketplace and the society.

Strategies:

- Broaden contextual experience and fully integrate with the new opportunities with the end user.
- Articulating the design vision for the company with tangible terms of references.

- Give way to the experiences beyond the major product line that the company is currently offering as learning from such experiences provides further uniqueness to innovation.
- Expand opportunities for interdisciplinary concept development at every stage of the product realization.
- Strengthen coordination between design and other key functions/ departments in the business.
- Enhance creative explorations and thereafter structured incubation process with a focus on developing new design competencies for the future.
- Extend the range of opportunities for intensive design research that are linked with company's future needs.
- Use the cultural context of the producing or supplying region in contemporary context.
- Develop more opportunities for design to become a cycle of activities in the organization instead of piecemeal interventions, if the efforts are to be geared towards brand building through design and its sustainability.
- Use the cultural, economic and social context of the user groups besides inputs about their information and technology profiles.
- Develop structures for the innovation systems so that approaches are understood and implemented smoothly.

Innovation through Collaborative efforts

While the business processes are becoming highly sophisticated, the time available to the development teams to come out with a diverse innovative range of design ideas that could satisfy the highly fluid trends is becoming limited. It is no longer easy as well as wise for designer alone to independently try developing a product that is efficient on all the fronts. A critical group of forward thinking professionals from diverse knowledge domains is almost unavoidable. Such a development team draws on interdisciplinary culture to seek new opportunities, making research, design creation and product functions integral to one another. The external environment in which we operate is a world of rapid change. An innovation driven design team must continually look for new frontiers of collaborations both in idea development and execution. This becomes easy if the design innovation is carried out in a collaborative but in a demonstrative mode. The later adds value to the participating human resource and continuously improves the quality of output through future attempts.

The goal should be to leverage diversified strengths across professional capabilities and exploiting opportunities to contribute to understanding of business environment, technological advances and emerging opportunities. Ensure that the benefits of this collaborative design experience help develop new set of know-how and skills.

STRATEGIES:

- Foster an environment that promotes interdisciplinary collaboration within the company and other stakeholders.

- Provide a supportive environment for design exploration activities. Sampling and new development that frequently is the complete onus of the design team only can become the collaborative activity across the departments.
- Promote design, technology, marketing and other function interactions, such as establishing a database of capabilities, and expanding and promoting forums for sharing ideas.
- Continuously evaluate the level of innovation competency within the set up and either reinforce or refocus the existing strengths to exploit comparative advantage. As the external environment changes, one must reshape existing methodology or initiate new level of collaboration to maintain or gain leadership positions.
- Biggest advantage of the collaborative development is that all the constituent participants are able to communicate their feedback in a contributory manner leading to systematic evaluation and improvement of infrastructure, including facilities, equipment, networks and market effectiveness of a product.
- Let the vocabulary of form, color, material manipulation and structure be demonstrated amongst all the collaborators so that a common visual language is followed at every level of change or modification.
- Bringing in a world view is critical for all the stakeholders for inculcating a commonly shared perspective of innovation. The aspect becomes very important in the area of made ups, conversion and putting together the collections.

Innovation through Comparative Advantage

Textile and apparel industry is throwing up many new business opportunities that seem very lucrative. However, trying to deal with every seemingly profitable product or just trying to add too many design variants of the existing product line will frequently add to confusion and the companies are not able to deal with it very effectively. It is always better that by the conceptual core the design collections or product range is smaller and more narrowly focused than those of other competitors. The design work at the stage of concept explorations could be wide but when it come to finalizing the concepts for further realization, the approach helps in developing a distinct comparative advantage. The company should make conscious resource deployments in order to exploit areas of comparative advantage. This provides ample scope for in-depth design innovations and the company gets compensated for its limitations in focused design range through strategic positioning, building from core strengths and leveraging the design resources through interdisciplinary interdependence. This kind of design planning and strategic approach, along with reasoned risk-taking by entrepreneurial and innovative designers, allows competing effectively with larger, better-endowed companies.

India fortunately has many such inherent advantages and they have largely been underutilized by the textile and apparel industry. Range of new innovative product possibilities due to our diverse textile sectors, raw materials, processes, immense resource of crafts and the unique cultural diversity, etc. can still provide us the much needed advantage in business and image building. Need is to aggressively develop and implement selected areas of focus that capitalize and add value to the strengths for which the resources are accessible.

STRATEGIES:

- Extend the available or easily available design strengths in the development process and use the information and Communication technologies effectively for the task besides consciously and continuously trying to expand the design vocabulary of the focus areas.
- Enhance or upgrade the existing design methodologies and approaches to excel in information driven society. Every established process can be questioned to discover innovation triggers and spots.
- Constantly pursue opportunities in alternative markets and new areas of consumer interests such as entertainment technology, experience-enhanced lifestyles, leisure and travel, and electronic commerce. Dynamic processes generate dynamic products for increasingly dynamic markets.
- Traditions and unique strengths are always there to be discovered. Invest actively in design research to match new sensibilities. This is so far the best design aid known to help the companies to keep the competition at bay.
- Technology has become an integral fact of life. Even the best of designers can not isolate themselves from it. Critically assess the impact of technology on society and individuals.
- Strengthen and maintain our information and communication infrastructure. The next major movement in textile design is going to be in the manner it is performed with the new IT tools and the ways in which people are connected in knowledge economy.
- Reinforce and better coordinate our current diverse design skills and traditions and cultural strengths in judicious mix with modern technology and knowledge for the development of unique products that are contemporary.
- Pursue opportunities with the human face of available knowledge. Areas such as stark economic divides, green design, ecology and sustainability should integrate well with the product thinking.
- Take advantage of our unique strengths to enhance our impact in holistic design thinking as it was visualized for most of the traditional textile design areas.
- Capitalize on our unique strengths in ornamentation, natural fibers, technique manipulation, and intricacy with attention to details, human skills and culture centric design to pursue an area of interdisciplinary strategic focus.

Expanding The Scope Of Innovations

Innovation as a trend has already set in and the market is getting filled up with many innovative products and designs that are bringing about a remarkable change in the way and manner we spend our lives around them. Today one needs to stretch the limits of innovation even further in order to succeed. In achieving its status as an innovative industry, the Indian textile industry will have to start taking selected but unique initiatives. These include: global approach to product styling, finishing, redefining quality, visual merchandising, and international collaborations for technology and know how. Further, as the industry continues its progression from a regionally distinctive to an internationally prominent textile industry, we must expand our design and innovation perspectives. This expansion is essential given the developments in information connectivity, growing economic integration and the increasing degree to which our competitors view themselves as global players. Design can expand the impact on this front by building on existing global as well as local strengths in order to compete effectively for qualitative business opportunities and future possibilities for the diversification.

STRATEGIES:

- Identify the targeted global markets to set a well articulated design brief and pursue its key focal areas for international activities.
- Select and define a range of innovative products that match the design brief and then start exploring the key process and product attributes that can be manipulated to bring in the uniqueness in the range to participate fully in a global scenario.
- Develop strategic partnerships in the areas of development with vendors, distributors industries and suppliers.
- Sensibilities of traditional resources, which have always, when correctly used, given a definite value to the contemporary textiles, must be furthered. Impact of such initiatives could further be enhanced by identifying strategic exposure, design research and technology transfer activities.
- Identify high-opportunity geographical areas that relate well to our capabilities.
- Efforts should be geared to integrate design studio ideas with pre and post production and also with merchandising processes. Not all the competitors would be able to channelize their efforts in this direction so easily.
- Convergence of technologies and diverse design skills are becoming a global trend now. The design team must continue to explore with multiple techniques and probably add a few more on continuous basis in order to offer new innovative product ideas.
- Innovating with the production set ups and developing completely new constructions and qualities that are not used elsewhere in the similar industry. The focus should be on building flexibility in systems and infrastructure.

Proactive Innovation through Networking

Networking is a common phenomenon in business. However, use of this as a strategy is seldom applied for design and development activities. Companies mostly prefer to keep their development efforts closely guarded. But, wherever tried the approach works well if the networks of vendors, suppliers and other related sources join hands for development of small parts of the whole picture. The progressive companies that aim at establishing global excellence are already looking at outsourcing very seriously, not only for cost reasons but also for collaborative innovations. In a market with continuously changing trends and dynamic product lines, the best way to sustain innovative development and profitability is to involve the yarn, fabric, accessory and other capabilities in seamless manner. Our ability to develop best innovative products is dependent on the professional, technical, economic, cultural and social vitality of our vendors and other networks. Occasionally, these vendors are not in a position to invest in design and development independently. A little help provided to them frequently leads to expansion of the range of materials that they have been supplying. In turn without much investment one gets the unique supply of raw materials or accessories that immediately adds value to the product range. A company serves its own interest by helping develop such constituents meaningfully to gain business opportunities.

STRATEGIES:

- Provide innovation leadership and strategic planning, matching the needs of the region with networked strengths.
- Allow faster commercialization of innovative design idea in order to recover the investments and get a lead.
- Use local issues and problems for creative concept development, design or innovative product diversification. This will ensure that the product is contextual and relevant to the infrastructure and resources.
- Any such design innovations should be test marketed in the alternative but relevant markets as well.

CONCLUSION

Design strengthens the logical but creative connections. A well-formulated design strategy frequently becomes the central driving force to provide product definition and satisfies the consumer. Successful design focuses on suitability of approach to the context and the product differentiation. Innovation has more to do with the approach and attitudes. Design innovation in particular does not necessarily mean an additional investment. Our own textile traditions are live examples that always give ample significance to innovation. The need is to explore our visual sensitivities and design vocabulary further.

The interpretation of innovation in this paper and the strategies suggested are tested and proven within the commercial framework, and have been based on the experience in the industry. However, innovation as a concept, logically escapes any fixed definition. In a sense the paper seeks to open up new understanding of innovation in the context of textile design rather than to close the debate. However, infrastructural constrains are the most relevant barriers against innovation and together we need to work beyond and through these barriers.

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Advanced Sewing Machines In Japan And Their Characteristics Of Seams

— I AJIKI, KYUYAMA, K SAKUMA & S SUZUKI

The thread adjustment on the conventional lock stitch sewing machine or overlock stitch sewing machine were performed by altering the pressing force of the tension regulating spring, so there was a problem in seam stability due to the variation of the tension imposed on the thread per stitch. In order to solve this problem, a thread feeding apparatus was developed to substitute the tension device, which can supply the needed thread per stitch actively for forming stable seam. In these sewing machines, it is necessary to input a significantly complicated manual operation for adjusting the thread tension device. Particularly, in overlock stitch sewing machine, it is more significantly complicated to obtain a good balance of the tension between the threads for the number of the threads increased.

The invention of the practical sewing machine is generally credited to the American, Elias Howe. Jr[1]. The fifth United States patent (No. 4,750)[1] for a sewing machine was issued to him on September 10, 1846. The machine used a grooved and curved eye-pointed needle carried by a vibrating arm, with the needle supplied with thread from a spool. Loops of the thread from the needle were locked by a thread carried by a shuttle (bobbin case). This is said to have originated the lockstitch seam.

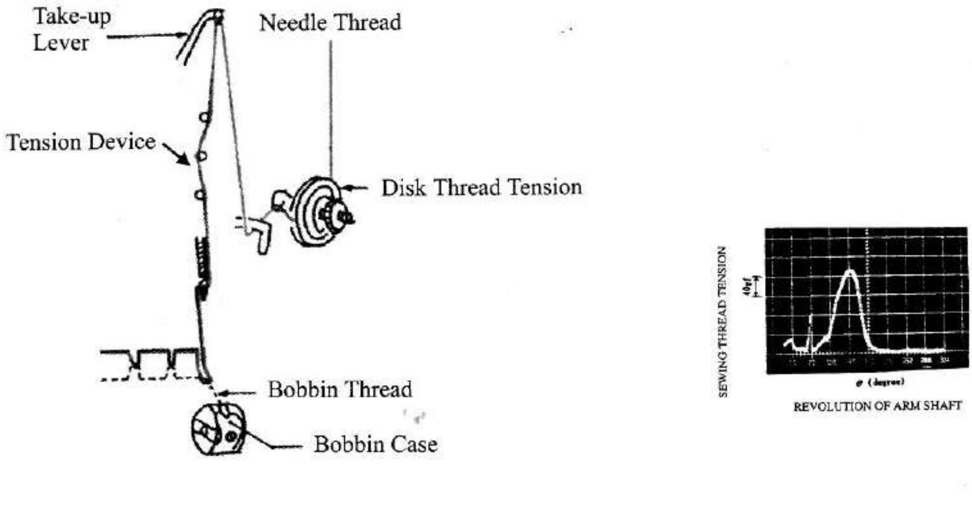

Figure 1 Conventional lock stitch sewing machine

Figure 1 (right) shows an example of tension waveform of the sewing needle thread during one revolution of arm shaft. The peak tension is called the take-up tension and is an important factor to make a good stitch.

The conventional lock stitch sewing machine or overlock stitch sewing machine is provided with a thread tension device comprising a pair of thread tension discs held between thread tension springs at a predetermined pressing force, thereby holding a thread between the thread tension discs and adjusting a tensional force generated in the thread, at the time of forming a stitch by a needle or a looper to a predetermined value by means of the thread tension device so that a stitch can be neatly finished even if the type and thickness of the thread is changed. In this case, feeding of the thread is performed by drawing the thread tension device together with a needle thread take up or a looper thread take up and tightening stitches. In these sewing machines, it is necessary to input a significantly complicated manual operation for adjusting the thread tension device. Particularly, in overlock stitch sewing machine, it is more significantly complicated to obtain a good balance of the tension between the threads for the number of the threads increased.

SEWING MACHINE WITH AUTOMATIC THREAD FEEDING APPARATUS

Automatic Thread Feeding Unit for Lock Stitch Sewing Machine

The thread feeding unit installed in the sewing machine 7800 is shown in **Figure 2**. The turning from arm shaft is conveyed to main thread feeding roller through gear 1 and gear 2, then conveyed to sub-thread feeding roller by gear 3, and they turn as arrow respectively. The needle thread supplied from bobbin winding passes through thread tension releasing solenoid and the movable sheet from pretension and is clawed by thread feeding rollers, then through needle thread take-up comes to needle eye. Thread feeding sub-roller is pressed to main thread feeding roller by the pressure of spring. The thread feeding rollers turn with the turning of arm shaft to feed the needle thread to the needle thread take-up.

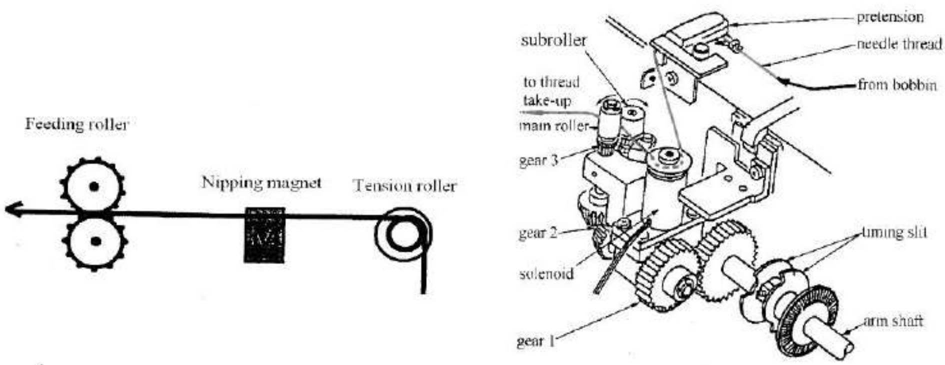

Figure 2 A Thread Feeding Apparatus for Lock-stitch Sewing Machine

If the electric current is turned on, the movable sheet is draft by the thread tension releasing solenoid. Since the thread tension is set up larger than the thread feeding tension caused by thread feeding rollers at this time, so the thread cannot be fed to the needle thread take-up. If the electric current is turned off, since the thread feeding tension caused by thread feeding roller is adjusted larger than the resistance imposed on the thread from bobbin winding to thread tension releasing solenoid, so the needle thread can be fed to the needle thread take-up.

NECESSITY OF MEASUREMENTS ON THREAD CONSUMPTION

Method of Measuring the Thread Length for Lock Stitch

It is difficult to specify the structural balance of a seam directly while sewing a fabric, so it is often assessed indirectly from the needle and bobbin thread tensions during sewing. If needle thread tension is higher than bobbin thread tension, the structural or geometric balance of the seam will be disturbed as the consumption of the needle thread is less than that of the bobbin thread. Structural seam balance depends directly on the relative needle and bobbin thread consumption[3].

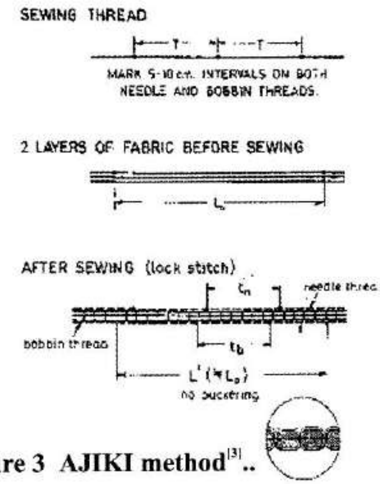

Figure 3 AJIKI method[3]..

There are two methods of measuring seam length and its balance: JIS method and AJIKI method[3]..

In JIS method[3], a unit length of seam is cut from the sewn sample, the needle and bobbin threads are extracted from the seam as gently as possible to avoid any stretching, then the threads length are measured respectively.

In AJIKI method (an advanced method), needle thread and bobbin thread are marked with equal intervals of length T in advance, and the marks will lie on the surface and underside surfaces of the seamed fabrics respectively after sewing, the thread consumptions can be calculated by measuring the distances between the marks. If the distances on the tow surfaces are equal, the consumptions of both needle thread and bobbin thread per stitch are equal, too. The number of stitches (N) contained in a regular marked interval on the fabric surface may be written as:

$$N = t_n \cdot n \qquad 2$$

where, n is the density of the seam (number of the stitches per unit seam length); and is the projected length of the marked interval.
The needle and bobbin thread length per stitch and , are each given below where suffixed "n" and "b" refer to the needle and bobbin thread respectively:

$$N = \frac{T}{N} = \frac{T}{t_n \cdot n} \qquad 3$$

$$\ell_b = \frac{T}{t_b \cdot n} \qquad 4$$

The total thread length in a stitch, et is:

5

Structural seam balance ratio may be defined as:

Seam balance $$= \frac{L_n}{L_b} = \frac{t_b}{t_n} \qquad 6$$

This method[3] has been used in checking its reproducibility by researchers[4,5], it is also available to examine the mechanical properties of seamed fabrics by checking whether seams are balanced.

Experimental Measurement of Thread Length for Lock-stitch.

The sewing machine for home-use (Singer-computer 7900) installed with automatic thread feeding apparatus was used to the present experimental work under the sewing conditions listed in Table 1.

Table 1.Sewing conditions for lock stitch

Stitch Length (mm)	3
Thread Count (Tex)	40 (Polyester 100%)
Sewing Speed (r.p.m)	400
Fabric for Sewing (2 Pieces)	Flano (Wool 100%)

RESULTS AND DISCUSSION

Comparison of the Thread Consumptions per Stitch

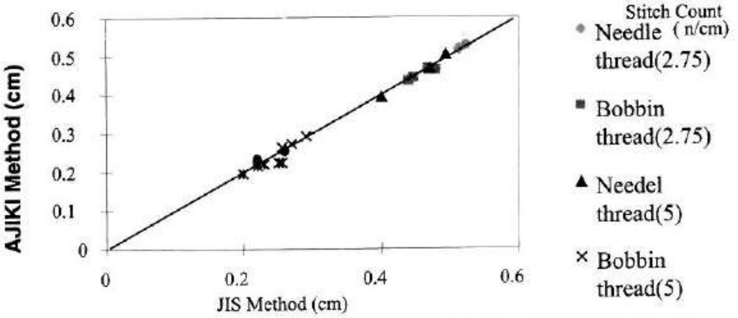

Figure 4 Comparison of AJIKI Method and JIS Method

The comparison of the thread consumptions per stitch measured with JIS method and AJIKI method is shown in Figure 4, and from which it can be seen that the thread consumptions are the same between the tow methods.

Relationship Between the Thread Consumptions, the Feeding Length of Needle Thread and the Tension of Bobbin Thread

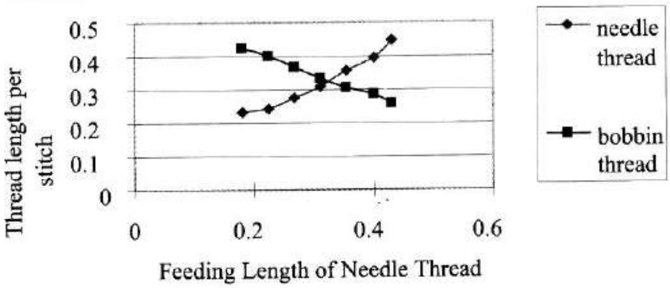

Figure 5 Relationship between the thread length per stitch and the feeding length of needle thread

Figure 5 shows the relationship between the thread length per stitch and the feeding length of needle of needled. X axis is feeding length of needle thread and Y axis is thread length per stitch. The length of needle thread and bobbin thread were measured with the method. It is reasonable that the needle thread length per stitch equal to feeding length of needle thread length. The point which the thread line crosses the bobbin thread line, means that the both lengths are equal, balanced seams and good seams.

When the bobbin thread tensions are changed from 30mN to 314mN, Figure 6 shows needle and bobbin thread length consumption per stitch. The consumption of needle thread is almost and steadily equal to the fed length of bobbin thread, but is not related to the tension of bobbin thread. Therefore, in order to catch the special feature of the stitch, it is appropriate to use the fed length replacing the thread tension.

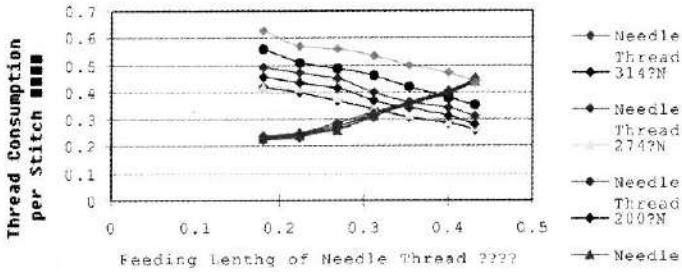

Figure 6 Relationship between Needle Thread, Bobbin Thread and the Feeding Length of Needle Thread

CONCLUSION

The outward appearance of the stitch and the thread consumption were invested and compared to those sewed with the traditional sewing machine.

(1) AJIKI's metod is used to the measurement of thread consumption and it is also available to examine the mechanical properties of seamed fabrics by checking whether seams are balanced.

(2) The consumption of needle thread is almost and steadily equal to the fed length of bobbin thread, but is not related to the tension of bobbin thread. Therefore, in order to catch the special feature of the stitch, it is appropriate to use the fed length replacing the thread tension.

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"Design And Prototyping" In The Fashion & Textile Sector : Powering The Value Chain For The Global Market

— IKERATH JOSEPH SAM

This paper addresses distinct issues that commence with the unchallenged fact that the Apparel and Textile industry saw the first light of the business process outsourcing wave (today's so-called BPO's) and this spawned the establishment of the large export and domestic industry we have in India today. Besides the design and prototyping and the retail activity (which happens more or less specific to the location) every other activity from fabric development & sourcing to merchandising and manufacturing is already happening in India (and is still going through a consolidation driven by capability). As a nation our competency for operational efficacy (and tendency) could be seen in the various sectors by our ISO accreditations where the "design and prototyping" capability never blinked on the radars.

This paper would necessarily focus on the fashion & textile sector and emphasize our "design & prototyping capability" which is not tenable merely by highlighting our diversity and culture especially in the areas of art, design and the strength of the traditional textile industry, but also by the strength of our inherent textile & fashion design industry which is not only making an impact on the domestic market but strong inroads in the strong retail driven markets like Europe, US and Japan.

This being the key driver of the value chain would mean offering these services (design& prototyping capability) for brands and retail chains present in the developed and new markets but this requires a change in mindset which would mean re-engineering the confidence levels of the large brands by displaying the capability through the present interaction, the increased focus of our own government to promote this in 'key markets' as a 'key sector' with multi-functional capability & investment support, and to finally create a mechanism to understand the design-driven markets diligently so that the design function is treated as capability and not a fad!.

India is at the cross roads of 2 occurrences which are driven by the domestic and international retail industry- one is that of the opening up of the domestic retail sector and the other the increased dependence on India for the outsourcing of services and manufacturing by International retailers. This presents a threat to those who don't see an opportunity especially as the advantage this country offers is beyond that of low cost labor.

While conventionally on one hand over the last 25 years this country has seen the emergence of textile and apparel export as a major industrial enterprise on the other hand the domestic sector was dominated by home grown brands many of which are virtually extinct today or the ones that have been established firmly were backed by textile giants such as Madura Garments, Bombay Dyeing, Arvind Mills, Raymond etc for whom the investment in the garment/ apparel business were miniscule and not a priority. This also saw the emergence of 2 types of small &

mid sized entrepreneurs those who saw an opportunity in the International market and commenced sourcing and supplying to retailers, brands and importers overseas and another type which endeavored to tap the domestic retail market through stand alone or chain stores.

Over the last 10 years as various global initiatives such as GATT and its new avatar the WTO commenced outlining a timetable for the phase out for the quotas and proliferation of free trade these two areas (exports and the domestic market) saw an increase in the scale of businesses and at the same time a possibility for convergence. An example is the entry of various overseas non-fashion(food/fmcg etc) and fashion brands/ retailers into the Indian retail market such as Levis, Nike, Reebok, Mango, McDonalds, Pepsi etc where while they were franchised , adapted the International practices of their parent companies and contemporaries in other Asian countries. The brands/ franchised retailers commenced sourcing most of their merchandise from their Indian manufacturers/ sources instead of importing everything from overseas. While FDI in retail is still contentious in India due to the belligerent opposition from the local retailers what is evident is that this is inevitable and the opposition to do so would mean that the movement of goods and services from India to other countries too could be hampered in the long run.

INTROSPECTION & OPPORTUNITY

There are 3 key elements in the supply-chain of every product- Research & Design, Merchandising & Manufacturing, and Distribution & Retail. While the latter 2 have always been driven by competitiveness and opportunity, the research & design function have been executed by resources close to the market. As most of the world apparel trade has been US & Europe centric the R&D function has been executed using resources from within the market while competitive pressures have seen the migration of merchandising and manufacturing to low cost labor countries. At the same time the expansion of most of these brands & retailers to emerging markets saw the introduction of the same ranges across various markets with elements of localization introduced for faster brand acceptance. With the localization effort came the limited outsourcing of the R&D function and simultaneously the exposure of International trends, benchmarks and practices to the resources in these markets. At the same time in the area of manufacturing India and China have become threats to various other countries which is why they have united and requested the WTO & the US to extend the phase out of quotas for these two countries. While in servicing and manufacturing India has proven its expertise the opportunity in research and design is much larger especially as this drives the supply chain and the global retail market. Today most of the R&D, Academic and Scholastic support in these countries is extended by immigrants from India and China, be it in space technology, animation, management, IT, healthcare etc. This proves that with the right resource support, exposure and opportunity India can excel in the area of fashion/ apparel 'design and prototyping' as well as it continues to do so in other areas.

Our competence to execute this function stems from the following factors:

a. We are on the forefront of knowledge management and execution capability.

b. We have trained and qualified resources with exposure to International benchmarks and practices, with an increased understanding of the International retail industry. Today India has one of the largest number of fashion training institutes and schools in the Asian region.
c. Extensive skill base that can facilitate the R&D function such as access to a diverse fabric source, capabilities in dyeing and printing techniques, traditional weaving & handwork techniques, introduction of design tools and techniques, etc
d. Fast paced evolution of the retail industry and especially the local designer wear retail market estimated at USD 45 million poised to grow to USD 500 million in 10 years and the International acceptance and growth of this category especially through International retail formats.
e. Proven excellence and emergence as a service basin which has proven itself to the International market such as in engineering, pharmaceuticals, software, IT enabled services, etc.

MARKET TRENDS AND THE FUTURE FOR INDIA

In the US, Europe, Central America and Far East, 'technology' especially 'digital communication' has been on the forefront of reducing the gap between the R&D/ design and the merchandising-manufacturing function. Whereas earlier the retailers'/ brands/ agents used to transmit information on an order through facsimile and hard copy patterns today they transmit the same through email, EDI and electronic formats. With their dedicated manufacturers, JV partners, collaborative ventures the clients even shared the same ERP packages & online tools to expedite order/ re-rorder processing, information on sampling/ orders, execute iterative alterations, sharing of information on shipments/ commercials and for the effective management of the supply chain including vendors/suppliers/ancillary industries.

In the last 5 to 7 years the usage of CAD CAM in India and China increased with the development of this region as a key apparel supply base. This resulted in the permanent establishment of world leaders like Gerber, Lectra, Investronica etc in India which ensured that local manufacturers could digitally communicate especially in the area of prototyping and manufacturing with their principals abroad. The use of AAMA approved formats and inclusion of these in the academic curricula of the fashion institutes and schools guaranteed the usage of these systems by a majority of the manufacturers/ suppliers. Those who could not afford it used the services of the local partners of the technology partners in India- the success of the training schools set up by Tukatech, Reach Technologies, Magnum Technology etc to offer training as well as outsourcing services to this large segment much before the present BPO wave is an attestation to the opportunity this area offered.

The increased application of design tools in the fashion industry commenced with the textile sector approximately 10 years back- this was extensively offered as India was identified as a prime source of fabrics (cotton based) and with this opportunity came a large number of suppliers who needed to differentiate using these tools to offer variety and something new to their overseas clients/ principals. The design tools were offered in the areas of printing, weaving & texturising supported by the manufacturing capability to produce these designs. While Indonesia, Taiwan, S.Korea and China excelled in this area, in India this trend was the driving force to the usage & integration of technologies across the spectrum from fabric design and manufacture to the point of retail- some of the pioneers in this were Arvind Mills/ Arvind Clothing, Raymond, Aditya Birla/ Madura Garments etc.

In the last 5 years with the growth of the domestic brand and retail industry the technology providers saw that there was an opportunity area to offer tools and techniques which were offered to retailers and brands in the US & Europe to those in India. These included those of design, merchandising, VM (visual merchandising), prototyping and simulation with web based interaction for collaborative interfacing between markets and elements in the supply chain. The increased usage of design & merchandising tools by home grown apparel brands and the curricula training of these by the design and fashion schools/ institutes ensured that there was the requisite skill to support the technologies offered. Simultaneously with the increase in clients exploring sourcing options out of India the emergence of a new interface called the 'buying house' started gaining prominence in the supply chain. The evolution of buying houses to work beyond the brief of overseeing manufacturing, quality and timelines into 'value adding' elements in the supply chain saw the emergence of activities such as sourcing of new raw materials and products, design & trend outlining, prototyping etc being done from India. The increased application of design & trend forecasting tools, interactive prototyping and retail forecasting saw a convergence in the activities that could be offered to both the International and Domestic markets.

This familiarity coupled with our strengths across the supply chain, gives us the requisite skill, access to know how and technology, experience and tools/techniques to be an ideal 'design & prototyping' hub. While broadly Design and R&D can never be completely outsourced, almost every retailer and brand of repute has been sourcing out of India for sometime now, and with the era of collaborative working having commenced in this industry India has the singularly largest opportunity (already as a global outsourcing hub for various other industries and apparel manufacturing) to be a key player in the global fashion industry.

BUILDING CAPABILITY AND COMPETENCY

The effort to become a key design and prototyping hub requires the build up of competency in the following areas through the usage of time tested and continuously evolving tools (most of these are available with Lectra, Gerber, Karat, Nedgraphics etc):

A. **Design & Specs:** In the current scenario computer aided design tools have evolved considerably to include creation of models in 2D & 3 D with the capability to execute refined and scaled sketching, mapping, rendering, and editing. The hardware and software is meant to be an extension of the hand and the mind because of which most of the peripherals and accessories are ergonomically designed to get perfect models &

prototypes. The product while being designed is visualized in 2 & 3 D with the option to place it in the environment that it will actually operate in & also test the fits and drape. The designing tools have the option for colors, textures, drape, and silhouette management. These tools can also generate technical specification sheets and product sheets. The current generation of CAD systems are highly evolved to adapt manufacturing constraints within the design process and can be used across fabrics, both woven & knits.

B. **Color Communication** One of the most tenacious challenges is the concept and communication of color. Color has always been a decisive element of fashion and the communication/ perception of this is as critical as the designing process itself. While trend forecasting plays an emphasis on this the very large spectrum of choices can be misleading yet a necessary evil for the perfect match. Both domestic and export houses use tools like the Pantone for references (and this too has been computerized) yet as the same color looks different in hard print from that of the soft copy 'color' communication is a critical subject that needs careful management. Further this needs to be effectively communicated to the user of this information whether it's the buyer, brand manager, marketing team etc. The color has to be specific for the substrate on which it is to be used and once done there are tools which can read the color digitally using a device called a spectrophotometer to create a "digital fingerprint" of the color or a "spectral value". This digital information can then be used two-fold: to communicate to the key players in the 'design decision process' so that lab dips can be generated and to be used internally within the organization.

C. **Presentation**- the presentation of designs along with the colors and swatches and also capturing the mood of the inspiration using picturesque depictions/ music and fabrics/ materials is a critical part of this process. This presentation (interim or final) captures the inspiration behind the collection that has been designed and needs proper demonstration using the right CAD tools. The culmination of the process has to be done using story board and cataloging tools which is also a compilation of all the material, color, elements and context used.

D. **Technical Design** This includes translation of the 2 & 3 D sketches/ designs into technical specs for the generation of patterns to create the prototypes to test the fits and drapes. Pattern making must be achieved with the correct technical specifications for the most accurate fit. The key manufacturing parameters along with the styling constraints are used as a benchmark when patterns are generated along with the size sets and variations.

E. **Virtual Merchandising** The designs along with the technical information can be used to create a 3D virtual garment, a range and subsequently merchandised in a simulated retail space to examine the product line long before it hits the stores and also this information can be used by the VM team to create the store look so that props and other displays/ interior design changes can be simulated and created on a larger scale for a larger number of stores and this activity can then be simultaneously done along with the final introduction of the range in the market.

F. **Virtual Prototyping** This is an interesting and a simultaneous process along with the presentation stage where real life simulation happens on the actual fabrics to be used. This is possible with the use of digital printing and this process helps in evaluating the design by others involved in approving the designs as well as the manufacturer (once approved) to have a reference point for the fabric, color, texture and processes required. The fabrics can also be used in catalog shoots, showroom presentations, VM and other forms of design evaluation.

G. **Collaborative Product Development** Design outsourcing can be successful only when the resources close to or within the market can interact collaboratively with the resources executing the design activity which would mean that in the current context 'the design process/ product development process as a whole' needs a collaborative approach. The product development process can be successfully outsourced only when the right tools are used to integrate and communicate the design evolution and the process involved that led to the desired outcome. The product development process is documented using a PDM (Product Data Management) so that if confirmed the manufacturing objectives are also efficiently attained without repetition of the whole process again. The PDM also enables different elements in the supply chain to work on the style cohesively at all stages of the design and prototyping cycle. The use of EDI & the web has facilitated this to a large extent.

H. **Online Exchange Platforms** The web has the potential to be the largest facilitator of the design and prototyping outsourcing opportunity. With the evolution of the above mentioned tools the capability to interact and iterate on ideas/ concepts can facilitate the faster evolution of the designs. Like in architecture where architects from across the world can interact on International & outsourced projects through the web by using AUTOCAD, fashion design & prototyping tools too are evolving to make this facility more interactive and efficient.

NON-TECHNICAL REQUIREMENTS: 'BENCHMARKING' CAPABILITY, BUILDING THE 'COMFORT LEVEL' & THE EXERCISE OF ' POSITIONING'

If the above requirements are conceptually fulfilled through the installation of the right tools, procedures and practices then a firm is a little more than half way to position itself as capable to handle outsourcing for the 'design and prototyping function'. While design & prototyping separately and together are offered even by independent designers, service bureaus, and freelance agencies, the combination of success factors mentioned (the tools, techniques, approach and positioning) is required to make the model work on a long term.

Off-site delivery capability (which is what outsourcing is about) has to be constantly 'benchmarked by measuring metrics' such as lead time for the design & prototyping cycle, market success of the designs and value addition beyond the original function (such as manufacturing, quality control and shipment/ documentation). This competitive attitude and focus can enhance the prospects for increasing business considerably especially if these metrics are shared with the customer.

Historical data shows that while independent designers can execute designs and presentation, they most often lack the infrastructure and capability for prototyping, simulation etc. Even with the right level of technology, which mostly service bureaus have (such as in the case of CAD services- digital printing and/ or pattern making etc) the indepth understanding of the market requirements is lacking and further the effort to build up the requisite comfort level to execute assignments of this nature (design oriented) is not easily forthcoming from either side. The 'comfort level' between the retailer / brand and the body to which the work has been/ is being outsourced has to be exceptional so that there is synergy and a high level of efficacy.

The 'positioning' factor is equally critical as the organization which executes this nature of work (design oriented) has to also be 'understood' as a firm of values, unbiased, respects confidentiality, and has a client management system in place that handles each client professionally and efficiently.

Conclusion

Some of the largest brands/ retailers in the world have commenced outsourcing design & prototyping services as their infrastructure costs are low, risks lesser and work can be modulated based on the way the business moves. From the perspective of the retailer/ brand they are looking at partners who have the requisite capability, the internal controls, propitious positioning and the ability to sustain the relationship through the right delivery mechanism and quality of work. For Indian business (who have a definite edge as we've seen above) especially in the aftermath of the quota phase out, their existing businesses (whether a buying house or manufacturer) should be leveraged to offer design and prototyping services by taking into consideration the above requirements and fulfilling some of the outlined key parameters.

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Innovative Approach in Apparel Manufacturing: Critical Chain

PRABIR JANA, ALISTAIR KNOX &
PRABIR BANERJEE

Apparel pre-production processes are network of multiple Inter-dependent activities, While the longest chain of activities considering task dependencies is called critical path, *Critical Chain* (Goldratt 1997) considers both task and resource dependencies. Traditionally critical path based time action calendar concepts have been used in industry for planning pre-production activities with a goal to deliver order within the scheduled delivery date. While such approach stress not being late, it does not promote speed-to-market driven performance either, a must in fashion industry. In fact, the start and finish date ensures that benefits of early completions are lost, and only late completions accumulate in the schedule. In the absence of a standardised pre-production process network, *elimination*, *concurrence* and/or *integration* approach will be too case specific to be applicable across industry. In this paper application of critical chain concept is being explored as a lead-time compression technique for the first time in apparel pre-production processes. While both the human side and the algorithmic methodology side of lead-time management is addressed in a unified discipline. It was found that some of the critical chain approaches like *pooled buffer* and *relay race* may not be applicable in true sense in a buyer-supplier adversarial relationship, but control of *multitasking* can help compressing lead-time.

Apparel manufacturing primarily starts with product development; colour, silhouette, fabric (structure, texture etc.) and target price of a style is confirmed at this stage, after that style is sent for sampling to different manufacturer (may be in different countries) to get an idea of actual achievable parameters. In this pre-order merchandising stage manufacturer is selected based on quality, delivery capability and price quoted. Then a confirmed order is sent to selected manufacturer with specification and other details of the style. During this post order merchandising stage manufacturer is expected to submit samples in actual production fabric and trims for 'seal sample' approval, which is to be referred as standards during production.

Initial indicators from a recent study (Jana 2003) reveals average leadtime (order confirmation to goods trucked out of factory) is approximately 80 calendar days. Out of total cycle time more than 76% of time is spent on pre-production activities and only 24% of total time available for actual production (cut to finish). 67% of companies polled by KSA (Parnell 1999) also said that Improvement of product development time was their number one priority.

The pre and post order merchandising (together known as Pre-production) activities in apparel manufacturing are characterised by people oriented functions. Activities are synchronized considering inter dependencies between succeeding and preceding activities to make the process network. A critical path consists that set of dependent tasks (each dependent on the preceding one), which together take the longest time to complete. Critical path based time and action calendar concepts have been used in apparel manufacturing for scheduling pre-production activities with a goal to deliver order within the original delivery date. Some saw benefits of linking critical path events to the start of manufacturing, as this is perceived as the end point for any significant uncertainty in the supply chain, and is mostly under their control, while others prefer linking events to actual delivery dates, as start of production was not that critical to a sourcing company using several offshore cut-make-trim (Strangwick 2004). Lead-time reduction in the existing network is only possible by *elimination* (Remove a process), *compression* (Remove time within a process), *integration* (Re-engineering interfaces between successive processes) or *concurrence* (Operate processes in parallel) (Towill 1996).

It is important to note that the pre-production process networks are unique for every single enterprise, every single buyer, even sometimes for every single order (Jana et al 2002). In the absence of a standardised pre-production process network, *elimination*, *concurrence* and/or *integration* approach is too case specific to be applicable across industry (Jana et al 2002). In an effort to explore a generalised or standardised solutions/techniques that can be applied across the industry a time compression technique called *Critical Chain* was selected.

WHAT IS CRITICAL CHAIN AND WHY CRITICAL CHAIN APPROACH?

Dr. Eliyahu Goldratt introduced the first significant new approach, *Critical Chain* to project management (Goldratt 1997). The approach addresses both the human side and the algorithmic methodology side of project management in a unified discipline. Like project management environment pre-production activities in garment manufacturing are also primarily human driven. Further more some of the Critical Chain characteristics have commonalties with garment pre-production activities like reverse scheduling, multitasking, as late as possible scheduling and resource dependencies.

HOW NORMALLY HUMAN BEING WORKS….

Task Estimating: While estimating task duration, people worry about the effect of unplanned work interruptions and generally add hidden safety. A 10-day task duration may have 5 days of safety. The safety is called hidden because the task is entered in the project as a 10-day task. It's perfectly reasonable to have safety factor (especially with third party activities), but being hidden, often the purpose is lost.

Student Syndrome: General human nature is to put off starting of any task until the last minute, thus eating away the hidden safety buffer in the beginning. Unfortunately, if the task then faces unplanned work interruptions then the task will overrun estimate no matter how hard one works, as there was simply not enough safety left to recover.

Parkinson's Law: Most of us have heard about Parkinson's Law and seen it in action on projects. Work expands to fit the allotted time. If a task is estimated at 10 days, it usually doesn't take less, people will simply adjust the level of effort to keep busy for the entire task schedule.

Multi-tasking: Most of us work in a multi-project environment. We all have experiences of having to stop working on one task so that progress can be accomplished on another task in another project. Often, we wonder if all this jumping around makes sense because it comes with the penalties of reduced focus and loss of efficiency. Resources tend to migrate between projects in response to the latest, loudest customer demand in an attempt to keep as many customers satisfied as possible. This focus on showing progress on as many active projects as possible is the major cause of multi-tasking.

No Early Finishes: It is important to notice that tasks seem to either finish on time, or late, but rarely early? As conventional wisdom rarely reward early finishes. In fact, early finishers often being accused of sandbagging their estimates instead of being rewarded for completing ahead of schedule (Goldratt 1997). In this environment, people worry about their future estimates being cut based upon history so they quietly enjoy the lull, and officially finish on schedule on time.

Traditional work environments stress not being late, but they do not even promote being early. Which encourages hidden safety, the student syndrome, and Parkinson's Law effects.

Traditional Critical Path Concept vs. Critical Chain Concept

In traditional project environment tasks are scheduled as-soon-as-possible (ASAP) from the project start date. Every task has a published start and finish date. While this task scheduled start and finish dates seems logical, it does not promote speed-to-market driven performance. In fact, it ensures that early finishes are lost, and only late finishes accumulate in the schedule.

Let's elaborate upon the salient characteristics of critical chain concept while applying to project environment.

Task Estimating: Task is estimated at per actual working days (without buffer). The buffer days are then cumulated and added at the end of network or at important milestones. As pooled buffers are known to everyone (unlike hidden) time management is transparent.

As-Late-As-Possible Scheduling: Tasks are scheduled as-late-as-possible (ALAP) based upon the target end date. There are benefits as well as drawback to delaying project work as-late-as-possible:

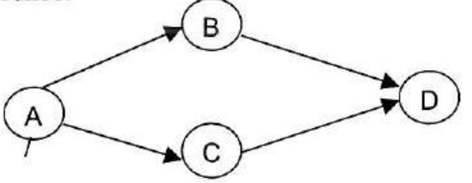
- Using a production analogy, work-in-progress (WIP) are minimized and not incurring costs earlier than necessary.
- From the project manager's viewpoint (in apparel pre-production scenario), there is better focus at the critical start of the project because there simply aren't as many tasks scheduled to start.

And one drawback:

- As all tasks are critical during tracking mode. An increase in duration of any task will push out the project end date by the increased amount.

Relay Race Approach: This means that when one task is getting close to completion, next task's resource should be on the track and ready to go as-soon-as-possible after the preceding task completes. This relay race approach means de-emphasizing the scheduled start and finish dates of tasks rather and concentrate on triggering their preparation and start on the preceding task's progress. Importantly, once a task is started, the resources work as fast as possible towards completion without clocking themselves to the scheduled finish date.

Resource Constraint & Allocation: Critical Chain is defined as the longest chain of tasks that consider *both task dependencies and resource dependencies*, whereas Critical Path is defined as the longest chain of tasks based upon *only task dependencies*; this is a subtle, but important difference.



Picture One: Critical Path Concept

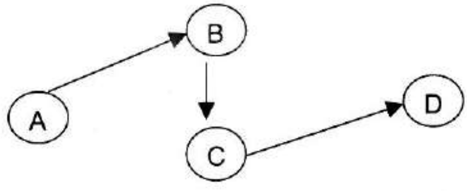


Diagram Two: Critical Chain Concept

Critical Chain recognizes that a delay in resource availability can delay a schedule just as a delay in dependent tasks. The following example illustrates the problem better. Let's imagine there are 4 tasks A, B, C and D with task dependency shown in picture one. Time estimates for each tasks are A = 2, B = 3, C = 1 and D = 2 man-days. One common imagination in Critical Path Concepts is resources are freely (infinitely!) available, that means if 4 different persons are available then the project would take 7 man-days to complete, A-B-D being the critical path. In practical circumstances resources are not aplenty, let's imagine task B & C have to be done by same person. So with resource dependencies (i.e. only 3 different persons available) the same project would take 8 man-days to complete. This phenomenon is very common in garment pre-production environment, where tasks per style averages 50-60 and only 5-6 executives manages all. Moreover multiple styles/orders run simultaneously and fewer personnel manage it. Ideally all the time n action calendars of different orders should be integrated into one integrated time n action calendar that takes into account the time available for resource people. Thus activities can be prioritized and executed with better time management.

CRITICAL CHAIN APPLICATION IN APPAREL PRE PRODUCTION PROCESS: CASE STUDY I

Pilot experimentation of Critical Chain concept in Silvershine Apparels was executed during year 2000 to explore it's potential in apparel pre-production. Silvershine Apparels is a $ five million turnover company with exclusive in house manufacturing facility. Network diagram from order confirmation to start of production is being mapped with SKU proliferation due to style (half / full sleeve), size, fabric and embroidery colours. The entire pilot was carried out by manual scheduling and tracking and not using any software program. Task estimating, ALAP scheduling and relay race approach was successfully exercised, while resource allocation and integrated network approach was unable to implement due to complexity of scheduling and tracking manually.

Set Up Mode

- Three styles (including the Connors Top) were selected for experimentation. Post order merchandise activities were monitored for all three orders.
- The critical chain concept was briefed to all team members and time for each tasks estimated.
- Develop a plan of all activities (task dependencies network or PERT diagram) backwards from the target delivery date for all three orders. Each task is scheduled as late as possible (ALAP). Buffers are inserted at different milestone levels. (Refer appendix XI for details about the order)
- Two schedule dates for each task were noted; first one as per critical path (ASAP) concept and second as per Critical chain (ALAP). This is done to compare actual with both at end of study

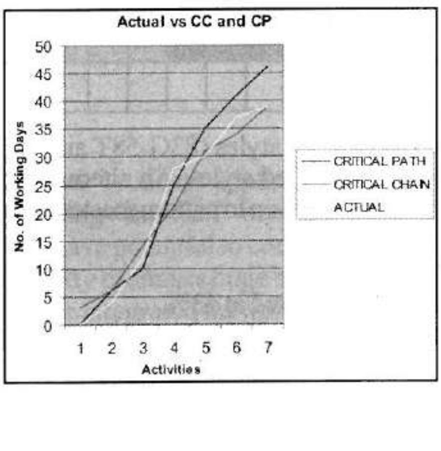
Follow Up Mode

- Relay Race Approach was followed; no due dates for each tasks, but finish as early as possible and handover to next person for next tasks. As the order activities moved forward respective executives were pre-informed and prepared for tasks to arrive, thus ensuring prioritization and speedy execution of tasks.

DATA COLLECTION AND INTERPRETATION:

The network diagram for Connors Top was modified to critical chain network by scheduling activities ALAP and inserting buffers (appendix A). Picture shows each activity durations, above every arrow, project buffer and the total order completion date. Then scheduled start/end date as per critical path and critical chain was compared with actual number of working days to complete the style Connors Top (appendix B). While mapping the actual and scheduled dates (Figure 1.0) it was observed that order was completed well before time as per critical path.

Figure 1.0



MULTITASKING IN PRE PRODUCTION PROCESS: CASE STUDY II

Pre-production activities in Delta Fashions & Silvershine Apparels were observed for one week to find out where multitasking was happening. Three activities namely CAD and pattern making in Delta Fashions and sampling in Silvershine Apparels were selected for observation. The minute to minute activities of all the three departments was collected for one month including the lunch breaks. Data was collected for 1 months involving 2-pattern master, one CAD operator and 3 sampling tailors. Explained below activities of pattern maker against time scale. Figure 2.0 shows pattern master involved in multitasking, Style W231 and 2PIE was abandoned half way and another two new styles (83G-58T and Jumper) were worked on before coming back and complete the half finished styles. An alternative scenario is presented in table below [Figure 3.0] if proper priority was given to pattern master and multitasking were avoided.

Figure 2.0 Pattern making activity in multitasking environment

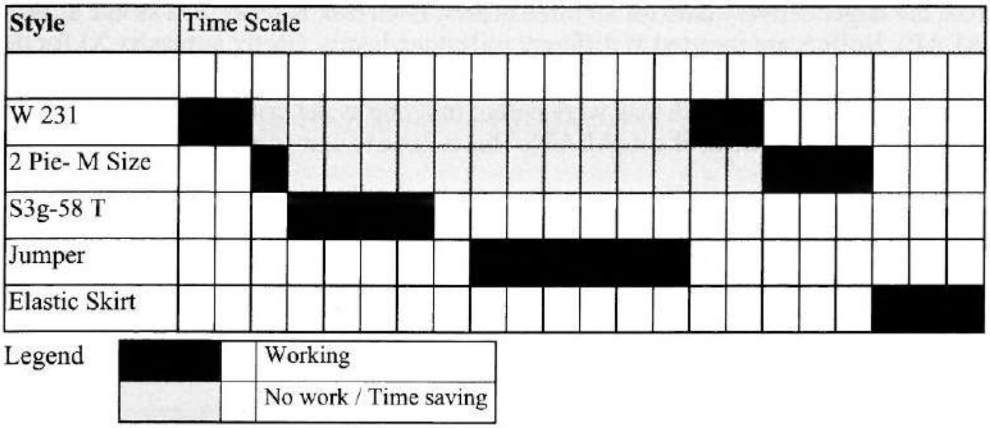
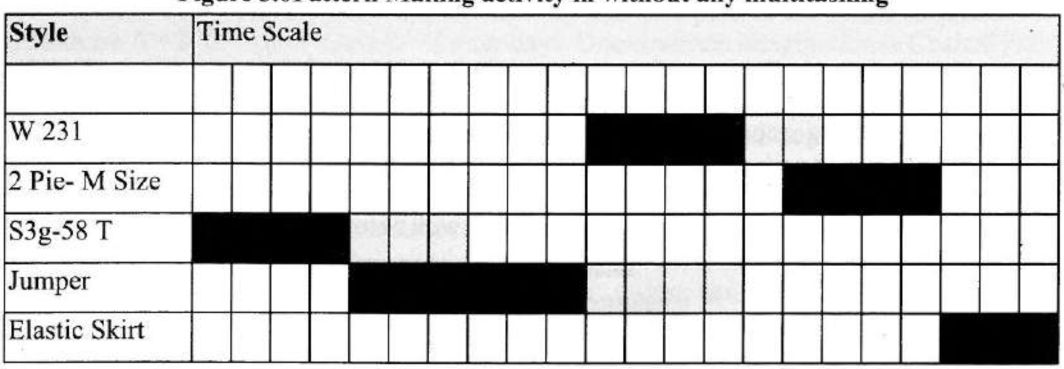


Figure 3.0Pattern Making activity in without any multitasking



The study result is summarised below:

- The average focusing loses is measured at 43%.
- The increase in lead-time of a particular task can be as much as three days instead of two hours.

- For pattern master the time lost on multitasking was 32.85%.
- The time lost on multitasking by CAD department was 38.80%.

LIMITATIONS OF CRITICAL CHAIN APPROACH IN APPAREL MANUFACTURING

In spite of its unique unified approach and reported success in project environment critical chain approach has its own limitation in apparel pre-production, majority of which is due to adversarial relation between different echelons in the supply chain.

Parameters	What it Means	Apparel Pre Production	Way Out
Task Estimating	Actual time duration for a task without adding buffer	Difficult to measure majority of tasks accurately due to their nature.	Slash certain % from time quoted.
Pooled Buffer	Buffer time from individual task is slashed and added for a group of tasks	Delay in one task has to be compensated by hurrying other tasks.	Encourage team performance rather individual target
Relay race approach	No individual due date, only project completion date. Complete as soon as possible once started.	Buyer set individual due date for certain activities may create problem.	Milestones can be set in accordance with buyer due dates. Treating individual milestones as different projects.
No Multi tasking	Set priorities for individual project. Complete project one by one.	Due to batch processing of certain tasks (ease of operation and increasing efficiency), multitasking may not be totally avoided. Some orders may complete before time (but buyer does not give any credit), while some order may get delayed (where buyer may penalize).	Group orders from same buyer and avoid multitasking within.
Scheduling ALAP	All activities scheduled as late as possible.	Third party activities may be vulnerable (as no buffer time is left once something goes wrong)	Make executives accountable by conferring them responsibility with authority.

CONCLUSION

While traditional "time-action-plan" concept application in pre-production activities tries to control lateness while still breeding "me-first" mentalities, critical chain approach actually induces team-working spirit and have potential to compress the time further. The first ever pilot experimentation in garment industry promises huge benefit by planning schedule and prioritize tasks based on a common-resource integrated network. In a multi-style operation environment, minimizing or eliminating multitasking can result considerable gain in internal activities

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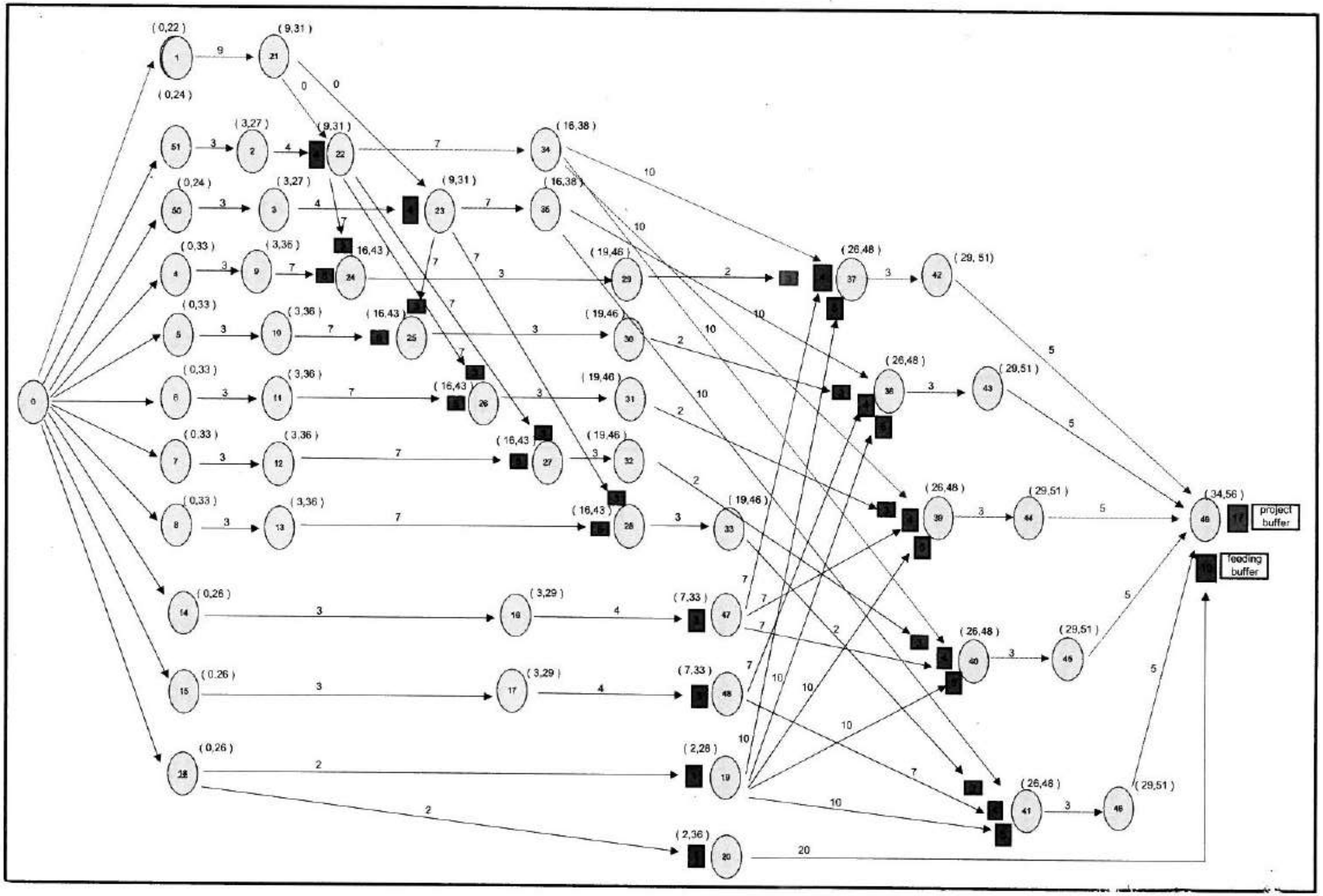
Appendix A



Appendix B

NO	ACTIVITY	CRITICAL PATH ASAP		CRITICAL CHAIN ALAP		ACTUAL START DAY	ACTUAL END DAY
		START	END	START	END		
0	order confirmed	0 DAY - 4 MARCH					
1	fabric quality approval	0	9	5	14		
51	lab dip for approval - petal pink	0	6	3	6	0	4
2	lab dip approval - petal pink	6	7	6	10	4	10
50	lab dip for approval - margerita green	0	6	3	6	1	4
3	lab dip approval - margerita green	6	7	6	10	4	11
4	fit for approval - L/SL - IG	0	6	8	11	1 7	7 10
9	fit approval - L/SL - IG	6	13	11	18	7 10	7 30
5	fit for approval - L/SL - TG	0	6	8	11	1 7	7 9
10	fit approval - L/SL - TG	6	13	11	18	7 9	7 18
6	fit for approval - L/SL - LG	0	6	8	11	1 7	7 9
11	fit approval - L/SL - LG	6	13	11	18	7 9	7 17
7	fit for approval - S/SL - TG	0	6	8	11	1	7
12	fit approval - S/SL - TG	6	13	11	18	7	7
8	fit for approval - S/SL - LG	0	6	8	11	1 7	7 10
13	fit approval - S/SL - LG	6	13	11	18	7 10	7 16
14	embroidery for color design technique - petal pink	0	6	10	13	5 12 37	12 17 38
16	embroidery color design technique approval - petal pink	6	10	3	17	12 17 38	30 30 43
15	embroidery for color design technique - margerita green	0	6	10	13	5 12 37	12 17 38
17	embroidery color design technique approval - margerita green	6	10	3	17	12 17 38	30 30 43
18	accessory ordered	0	2	13	15		
19	main label, loop label, wash care in/h	4	24	16	26		
20	hanger hangtag in/h	4	24	9	29		
21	fabric knit	NA					
22	initial processed dyed fabric in/h - petal pink	10	25	14	21	12	28
23	initial processed dyed fabric in/h - margerita green	10	25	14	21	12	28
24	size set sample for local approval - L/SL - IG	25	19	23	26	37	39
29	size set sample local approval - L/SL - IG	31	33	26	28	39	45
25	size set sample for local approval - L/SL - TG	25	19	23	26	37	39
30	size set sample local approval - L/SL - TG	31	33	26	28	39	45
26	size set sample for local approval - L/SL - LG	25	19	23	26	37	39
31	size set sample local approval - L/SL - LG	31	33	26	28	39	45
27	size set sample for local approval - S/SL - TG	25	19	23	26	37	39
32	size set sample local approval - S/SL - TG	31	33	26	28	39	45
28	size set sample for local approval - S/SL - LG	25	19	23	26	37	39
33	size set sample local approval - S/SL - LG	31	33	26	28	39	45
34	bulk fabric in/h - petal pink	25	35	21	31	28	45
35	bulk fabric in/h - margerita green	25	35	21	31	28	45
37	pre production sample for approval - L/SL - IG	35	41	31	34	30	37
38	pre production sample for approval - L/SL - TG	35	46	31	34	18	37
39	pre production sample for approval - L/SL - LG	35	41	31	34	17	37
40	pre production sample for approval - S/SL - TG	35	46	31	34	16	37
41	pre production sample for approval - S/SL - LG	35	41	31	34	16	37
42	pre production sample approval - L/SL - IG	41	46	34	39	37	45
43	pre production sample approval - L/SL - TG	41	41	34	39	37	45
44	pre production sample approval - L/SL - LG	41	46	34	39	37	45
45	pre production sample approval - S/SL - TG	41	41	34	39	37	45
46	pre production sample approval - S/SL - LG	41	46	34	39	37	45
47	bulk embroidery in/h - dolores top ppink	10	25	20	27		
48	bulk embroidery in/h - dolores top m green	10	25	20	27		
49	production start	46		39			
	production 10%						

Indian Competiteveness In Global Context

VIJAY BHALLA

India is on the threshold of emerging as a major player in the Global Textile Market. Several significant changes have taken place that reinforces this confidence. Some of them being -

1. There has been a major shift in the Policymaking. Though much delayed, the changes have been instrumental in positioning "Indian Textiles" as the leader for growth of Manufacturing Sector in India (Ref: *Table 1)*

2. While for rest of the world tha Quotas will stand scrapped at the midnight of Dec.31st 2004, China will continue to remain under quota regime for another two years. This is expected to benefit India in a big way and will counter the damage caused by delayed correction of policies of Indian Textiles.

Table 1. Policy Initiatives

Investment Targets	Rs.60,000 Crores(US$13bn.By Year 2010)
FACILITIES	1) Foreign Equity Participation Through 100% Automatic Route For Foreign Direct Investments (FDI). 2) Concessional Custom Duty- Schemes Like "Target- Plus". 3) Rationalisation Of Duty Structure- No Excise Duty Applicable. 4) De-Reservation Of Woven Ready Made Garments From SSI Sector.
PROGRAMME & POLICIES	1) Modernisation Of 2.5 Lacs Power Looms In Decenteralised Sectors. 2) Introduction Of 50,000 Shuttle-Less Looms ..High Priority. 3) Re-Inforcement Of Technology Up-Gradation Scheme. 4) Launch Of Cotton Technology Mission
FEW SUGGESTIONS FOR CHANGES	1) De-Reserve Knitted Garments From SSI Sector 2) Hasten Up Labour And Land Reforms 3) Lower Down Duties On Imports Of Capital Goods And Intermediates

Source: Budget 2004-2005

1. The world (including India) had a bumper cotton crop this year. The total world crop this year are estimated to be 23.93 mn MT as against 20.52 mn MT of last year indicating a growth of more than16 %. Indian crop is estimated by CAB to be 210 lac bales v/s 175 lakh bales (growth of 20%) last year.

2. Domestic Retail Markets in India is growing at a rate of more than 20%. Textiles and Clothing shall stand to gain as a major beneficiary with this market expansion. 289 new retail malls are expected to be started by 2007. Major Metros such as Delhi, Mumbai, Bangalore etc. stand to gain from this.

Global Cotton Crop

	Crop In (Mn. MT)		
	2002 -03	**2003-04**	**2004-05***
Opening stocks	10.24	7.99	7.31
Production	19.26	20.52	23.93
Total availability	29.50	28.50	31.23
Consumption	21.40	21.53	22.12
Ending stocks	8.10	6.98	9.11
Stock/use ratio	37.85	32.40	41.20

WHAT ALL IS HAPPENING IN INDIA

Not awaiting Jan.1, 2005, the Indian Textiles and Clothing are undergoing a hurried change.

a) Textile and Apparel sectors are undergoing Structural Changes. Indian apparel companies are hiring Expert Managers (at salaries US $80,000/125,000) in production, design and HR management. (Rs. 35 lac-60 lacs per Annum). Investments have begun after a long holiday in new technology, expanding capacities and forming joint ventures. Big growth is being envisaged in technical textiles e.g. Non-wovens, owing to increasing domestic affluence, growing health consciousness among Indian population and also the cost effective production of synthetic fibers in the country. Home Textiles is another area where domestic demand for branded and quality products is showing signs of booming. The fast growing automobile sector is fuelling the demand for automotive textiles.

b) Buying houses like Walmart, Target, GAP, JC Penney, Nike, Levis etc. are in the process of reinforcing their presence in India. Their focus is on few Indian companies with Larger Volume Capabilities.

c) Retailers like Macy's, G-star, Sara-lee, Fruit of the loom and a host of other US and European buying houses are entering India

d) High End Fashion Labels like Ermenegildo Zegna, Chanel, Fendi, Valentino etc. have started opening outlets in India. Other brands like Dolce & Gabbana , Versace, Donna Karan , Prada are evaluating the market . Launch of these collections will set new quality standards for Indian manufacturers for Domestic Consumers.

e) Estimates of growth for Indian Fashion and Luxury Textiles market is has been pegged at Rs.1000 Crores by 2010.

f) In last 5 years, 469 old mills in India had closed down. Modern mills and new modern facilities have started emerging.

g) Govt. of India has prioritized focus on Infra Structure to further consolidate the manufacturing sector. In the next five years, nearly 30,000 Kms of World Class Roads will be built and six top class International airports and 12 new Seaports will be put into operation.

COMPETITION - ACTIONS & DEVELOPMENTS

Indian Corporations are gearing up to face Global Competition square in the face. Some of the high lights are :

- Abhishek Industries Ltd., a major exporter of towels from India to US completes 100% expansion. Ready, on bang for Jan.1, 2005. Though, this is one company that grew with value-added end product during quota regime itself.
- Welspun India eyeing to secure Rs. 3500 million home textile by 2006.
- Vardhman Spinning and General mills Ltd. has initiated merger with Mahavir Spinning, another group company to create 1st mega merger in Indian textiles. The company plans to invest Rs.725 crores (US $160mn.) to set up a Modern Integrated Textiles Unit in M.P.

Major gains have been seen on most textile stocks indicating that once again Textile is a happening industry in India and the engine of growth of the manufacturing sector.

Other Points Of View

An Opportunity Or Threat: -

As a result of quota regime coming to an end, North American and European region shall loose significant activity to low cost Asian Region. China , India & turkey are large nations and are among those who would be major beneficiaries. However opportunities coming India's way would depend on many factors.

It is being debated whether quota going-away is an " Opportunity or a Threat". It is true that quotas going away are an opportunity for various countries and not only for India. It is also an opportunity for importers of products to take benefit of a large Indian domestic market : But , Is it really large ?

In an overall perspective global trade becoming quota free is an absolute opportunity for Indian textiles. The only question shall be as to what degree can we make it happen.

China's Businesses : Impact On Indian Textiles:-

China is expected to lead the inevitable change. They had a head start of 12 years against India. Performance of India to some extent would be a great factor of Chinese aggression. However, China shall be under Q.R at least for another two years. Still, it's some catching up to do for Indian Industry. Whereas China would be aggressive for US market, India shall have Turkey as its competitor in European markets. Past performance in Japan and Australia shows that China has taken a share of 75-80% in these quota free markets. China has capabilities to become equally aggressive in other quota free markets.

China is into bulk exports. India shall gain in exports of fabrics, fashion garments and items like made-ups. Uncontrolled growth of textile industry in China looks to be coming to a halt or a slow pace. Chinese Banks have been directed to stop free flow of funds to unviable projects. Infrastructure inadequacy is "A New Surprise" affecting growth in China. There is a Severe Power Shortage in china at present. Textile units get power-supply 4-5 days in a week these days.

US have asked China to agree to a limit on T & C exports in a bid to head off petitions from US manufacturers.

It would be a Learning to see how these Issues are sorted out by CHINA? A few facts on China are given below:

Land Area	* 7th Largest Country in the WORLD.
	* 3.29 million sq.km
Population	* 1,092 million (2003)
	* 17% share of World's Population.
	* Second most populated nation after china
Share In GDP	* 8%
Foreign Exchange Reserves	US $ 121 Billion.
Share In Manufacturing	* 17%
Employment	*35 Mn. Directly
	*93 Mn. In-directly.
Federal Republic	*Heterogenous
	*29 states + 6 union territories
Gross Domestic Product (At Factor Cost)	US $ 474 Billion (2001-02)
GDP growth rate	6.5-7% **Target .. 8% PLUS**
Foreign Trade Exports.	US $ 43.8 billion.
Textile Exports.	US $ 13 billion

Large Population (as a market)-

Being a nation of 17% population of the world, it is felt that India would be targeted by global players in a focused manner. It is well understood by competition that Indian Textile Industry is very diversified and one billion people have very small purchasing power. Inherently weak Indian Textile and clothing industry will have very little response time to act and enhance competitiveness.

Urban textiles demand in India (33% population) is growing @ more than 8% quantitatively and around 7% by value. This is healthier, being more than GDP growth. However, the rural demand (67% population) is a dampener being just 0.39% quantitatively and 3.18% by value. This is a very price conscious market.

Overall textiles in India have much slower growth compared to GDP. As such it is felt that the threat of import opportunity is very limited. With opening up of boundaries (Export Thrust & Import Threat) , even domestic producers are improving quality and reducing prices. This would be another factor incentivising producing locally instead of importing in the comparative term.

The Indian Textile Industry. . Demand Perspective.

Fibre		URBAN			RURAL			ALL INDIA		
		2002	2000	CA GR %	2002	2000	CA GR %	2002	2000	CA GR %
Cotton	Q	11.26	9.72	7.92	6.42	6.20	1.77	7.77	7.11	4.64
	V	656.72	560.59	8.57	236.09	210.71	6.02	353.02	300.70	8.70
Pure Silk	Q	0.35	0.72	-25.69	0.04	0.71	-47.18	0.13	0.31	-29.0
	V	200.73	282.29	-14.45	21.74	47.60	-27.16	71.50	107.96	16.9
Woolen	Q	0.22	0.14	28.57	0.04	0.71	-47.18	0.12	0.11	4.55
	V	94.91	28.50	116.51	21.74	47.60	-27.16	43.31	16.84	78.6
Man Made	Q	2.24	2.28	-0.88	1.45	1.67	-6.59	1.67	1.83	-4.37
	V	208.49	149.77	19.60	92.45	72.39	13.86	124.71	92.29	1756.00
Blended/ Mixed	Q	10.79	8.54	13.17	8.75	8.47	1.65	9.31	8.48	4.89
	V	846.86	744.57	6.87	446.38	427.57	2.20	557.72	509.10	4.78
All Textiles	Q	24.86	21.40	8.08	16.74	16.61	0.39	19.00	17.84	3.25
	V	2,007.71	1765.72	6.85	820.11	771.07	3.18	1,150.26	1,026.89	6.01
Population Share				33			67			100

Small Size Enterprises

For last few years, markets not being vibrant, industry was not getting economical prices. It was a jobless growth. In the present scenario, good opportunities exist for mergers and acquisition in spinning segment and for segment leaders in other areas. To keep cost of outsourcing low, large buyers would prefer to buy from few large suppliers. Mergers and Investments shall lead to larger sizes.

Presently even large Indian companies are not large enough as per global standards. With limited scope of mergers in India, investment thrust is a "MUST" route.

Second Hand Machinery-

Second hand machinery comes cheap. Historically the Indian industry, both organized and not so well organized sectors had been picking up very old / very cheap machinery. such old equipment normally has much higher . "Per unit cost of Production" and "Quality is not a match at par" with latest technology of new equipment.

Resultantly, the product fetches lower price with higher cost of production.

Free Trade with Neighboring Countries

So far Pakistan, Bangladesh and Sri Lanka had free access and higher quota sanctions in US and Europe. They are much better placed considering the relative national economies.

Pakistan - Though similar structurally, is strong in spinning and weaving. Cotton of Pakistan is inferior and man made fibre capacity small.

Bangladesh - Trying to build up integrated 'T & C' base. It has no raw materials available locally.

India- India is stronger in overall product (design and quality). Needs to simultaneously focus on making Synthetic or Manmade fibre products more competitive to enlarge its basket. In the open trade scenario, the other factors, which would swing trade, would be factors like Country Risk, Product Risk and Service Risk.

India is much ahead of countries like Pakistan, Bangladesh and Sri Lanka in this comparison.

Table : Comparison Of Non Cost Factors.

A. Country Risk Factors.

H=0,M=5,L=10

	Bangladesh	China	Hong-Kong	India	Indonesia	Pakistan	Sri. Lanka	Thailand	Turkey
Domestic Market Availability Risk	H	L	M	L	M	M	M	M	L
Transportation & Customs Disruption Risk	H	L	L	M	H	M	M	M	M
Communication & Infrastructure	M	M	L	M	L	M	M	L	M
Investment / Political Risk	H	M	L	L	M	H	H	M	M
Ethical Standard Risk	H	H	L	M	H	M	M	M	M
Legal System & Judiciary Risk	M	M	L	L	M	M	M	L	M
On a Scale Of 10	10	35	55	45	25	25	25	35	35
RANK as per least Risk	**V**	**III**	**I**	**II**	**IV**	**IV**	**IV**	**III**	**III**

B. Product Risk Factors.

	Bangladesh	China	Hong-Kong	India	Indonesia	Pakistan	Sri. Lanka	Thailand	Turkey
Product Dev. & Guidance	H	M	L	L	M	M	M	M	M
Product	M	L	L	M	M	M	M	M	M
Production Management	H	L	L	M	M	M	M	M	M
Production Capacity Barriers	L	L	L	M	L	M	L	L	L
On a Scale Of 10 Rank as per Least	15	35	40	25	25	20	25	25	25
Risk	IV	II	I	III	II	III	II	II	II

C. Service Risk Factors

	Bangladesh	China	Hong-Kong	India	Indonesia	Pakistan	Sri. Lanka	Thailand	Turkey
Quota Applicability w.e.f. 2005	L	M	L	L	L	L	L	L	L
Raw Material Availability Risk	M	L	M	L	L	L	M	L	L
Factory Lead Time Risk	M	H	L	L	H	M	M	M	M
Minimum Order	H	H	H	M	H	M	M	M	M
Delayed Delivery Risk	M	M	L	L	H	M	M	M	M
On A Scale of 10	25	20	35	45	20	35	30	35	35
RANK	IV	V	II	I	V	II	III	II	II
TOTAL A+B+C	50	90	130	115	70	80	80	95	95
RANK	**VII**	**IV**	**I**	**II**	**VI**	**V**	**V**	**III**	**III**

Investments

As per US International Trade Commission, gaps in Indian domestic "Textile & Apparel Industry" and US $50 billion exports targets of Indian government are good investment opportunities. Indian government estimates an investment of Rs60,000 Crores (more than US $13 billion) in textiles by year 2008 / 2010. Indian Textile and Apparel is undergoing structural changes to improve competitiveness by investing in new technology, expanding capacity and by forming joint ventures.

Operational Excellence

Quota regime coming to an end would mean entry of more suppliers in the market. Share in the markets will have to be gained by competing with the "Least Cost Manufacturing" sources internationally. Hence pressure on prices and business cycles. This would be achievable with the only imperative of "Enhancing Operational Excellence".

Textile and textile product manufacturing companies will have to accelerate the actions on initiatives just begun in this direction. Issues of Manufacturing Competitiveness require actions on specific initiatives i.e. Enhancing product by "focus on quality and customer orientation" and Reducing costs across the business value chain.

On analyzing value addition at each stage for a consumer item e.g. a sheet set (home textiles), we can observe that-

Mfg. Stage	U.O.M	Weight	Value (I. Rs.)	Value (US $)	Value Addition (US $)	Value Addition (%)
1	2	3	4	5	6	7
Fibre	Kg.	3.0	150	3.20	--	5-6
Yarn	Kg.	2.35	250	5.43	2.23	4
Fabric-Grey (Wide Width)	Mtrs.	3.5	770	16.75	11.32	20
Fabric- Finished	Mtrs	3.5	1225	26.60	9.80	17
Made Up	Set	1	1350	29.30	2.70	4-5
Retail - Domestic	Set	1	2600	57	27.7	48
Retail In USA	Set	1		250	210	100

<u>Assumptions :-</u>

1) CTN fibres @ Rs. 50 per kg

2) % value addition = $\frac{\text{Value added}}{\text{Retail value}}$

As can be seen, maximum value addition takes place after Manufacturing at Retail Stage. This area of Cost requires partnership and business understanding between buyer & supplier to improve Supply Chain Efficiency.

Other cost areas to bring focus on profitability or improve competitiveness can be categorized as hereunder:-

Manufacturing costs: -

Cost attributed to Raw Materials, Labor, Utility etc. totally depend on internal focus of the corporate. The key areas to improve cost efficiency are: -

Manufacturing productivity: - It is generally observed that typical Textile Companies in India can drive up productivity levels through internal initiatives "appreciably". The key strategic factors in this regard are related to focus on core Organizational Capabilities / Competencies. e.g. Organizational structures with accountability. Improving manpower productivity (20-50%). Enhancing Level of Manufacturing Technology. Leveraging Information Technology effectively.

Power / Energy Cost : - This cost can be further sub-divided for better understanding into following- Captive vs. Supply Cost; Finance Cost on Captive Generation; Internal efficiencies of Energy Consumption. All these factors are internally controllable. With a number of policy incentives available the first two are very well manageable globally competitively. The third issue though the highest priority is addressed in a very secondary manner by the industry.

By competently Re-Engineering Energy Consumption centers and implementing them, our experience at BEC Enmas is that even in the most efficiently run manufacturing units, 3-5 % energy consumption can be reduced on daily & sustainable basis. Effectively, we have facilitated reduction ranging from 5% to 11% in different units. In a typical unit with Power / Energy cost being 10% of the sale value, a net 5% reduction in consumption means enhancing net profitability by 0.5%. Similarly 10% energy consumption reduction will enhance profitability by 1%.

Manufacturing Cost is the main component in spinning (almost 96-98%) and weaving (85-90%). The scope being very limited, these improvements will give a good relief. In the Processing, Energy Cost including "Water, Steam and Power" is a major component. In this area, the savings can be much more. In the case of apparel / made-up manufacturing units etc., 20-25%. cost can be reduced by improving operational efficiencies. This segment requires massive inputs on manpower training, being very labour intensive.

AGGREGATION

Indian textile industry can aggregate both supplies and procurement. This can enhance performance and reduce costs immensely. Mind Sets of Indian Enterprises need to be changed to accept this as a reality. Foreign buyers can accept outsourcing if an Indian company can successfully meet quality and timely delivery effectively. This however, will be possible only after credibility for brand India in both these areas is established. Relatively smaller and medium size companies "Can and Must" aggregate and consolidate procurements to bring down costs appreciably. e.g.-

Aggregate and buy raw materials e.g.-cotton and yarns together.
Aggregate and buy packing materials.
Aggregate requirements like logistics, (ocean freight, insurance, stores - items etc.) And initiate e-sourcing/ Strategic sourcing these services.
Aggregate and buy plant and machinery together. It can fetch even upto more than 50% reduction in value.

COST OF CAPITAL

This is now a non-issue. Indian organizations are "Re-structuring" these costs competitively. Alternatives are available to get Finances @ best Global cost levels.

State Incentives: For growth through New Investments / Expansions, alternatives exist practically to invest with negligible or nil finance cost on investment. Most of the state governments are strongly Incentivising Investments in textiles as a panacea for jobs (blue collar) creation. It's a very important political Imperative for them. This practically is a parallel route to recover investment made over a period of 10-12 yrs.

Labour Policies & Practices: Blaming the workers for productivity is a common phenomenon. Agreed , The Industry must ask for labour reforms. But at the same time ponder over the following-

In these Labour Intensive Manufacturing Units, there is no organized industrial engineering set-up. There is no scientific methodology to measure requirements. Investments in Training in Methods and Processes lead to major improvements in quality and productivity. Different Garment manufacturing units produce anywhere between 12 pieces to 32 pieces per worker in a given time. This is within the same region. Labour laws are also same.

Similarly there is good scope of rationalization in spinning, weaving and processing units. Efficiency in Production Management needs to be built in by Introducing aggressive "Industrial Engineering" practices; Retraining workmen for deployment; Focus on improvement in various Processes and Methodologies. e.g. Material Handing practices as followed currently are very weak; Increasing flexibility in Operations to improve man-hours utilization.

As said earlier, so far the scenario was no growth in jobs. Textile sector is India's largest employer after agriculture. Even as it is preparing for post quota-battle, it is fairly labour intensive. With investments being made, employment avenues have opened up. e.g.- A large

Export House recently is reported to have hired 6000 workers additionally. Total employment now is 31000. This is at par or more than large IT (InfoTech) companies.

When employment and textiles are set to rise by 15-20% by 2005, it is the right opportunity to undertake initiatives like retraining or rationalizing aggressively. Stringent standards instituted by overseas buyers backed up by social audits, shall work as good safeguards for workmen. These infact are working out well for industry also. At this stage, to take full advantage of job creating opportunities, opinion makers in the policy making need to be educated about it in a structural manner.

IN CONCLUSION

Operational Excellence can be created through enhancement of-

Operational Efficiencies.
Re-Engineer Product Quality & Product.
Re-define Capabilities-
Begin with Benchmarking against one's own Best Performance ever, as a continuous process on way to bench-making with the best in the world.
Reduce Costs through seamless work practices.
Re-enforce Marketing Systems, Markets and Customer Relationships.
Re-Structure Business Planning, Production Scheduling, Performance Review and MIS systems.
Re-invigorate innovation as a culture to define area of focus in respective organization.

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China Is No Threat To India Post-ATC: Facing Up To The Reality

— VINOD SHANBHAG & NANDITA ABRAHAM

The post-ATC spectre has evoked widespread anxiety globally among supplier nations, owing to their deep-seated fear of loss in trade shares in the future quota-free textile and clothing imports of Canada, EU and USA. India's exporters have been equally anxious. However, a host of studies through 2003, 2004 have highlighted that India will emerge as a major winner along with China, and some other minor winners. Winners will be those suppliers that have strong domestic supply chains or are proximally located to one. Losers will be all suppliers, without adequate supply chain strengths, that enjoyed administered advantage through quotas and preferential arrangements. With this foresight, this paper delineates a suitable product-market strategy for India to enable it to harness the unfolding, bright future in currently restrained markets.

When China was admitted to the WTO in late 2001, on the eve of the third stage of the ATC, it set alarm bells ringing in the textile and clothing markets of the world. Other exporting nations anticipated a threat to their trade shares, especially, in the restrained US, EU and Canadian markets. Earlier, in the prelude to China's WTO accession, several prognostic studies had painted a picture of China running away with world textile and clothing consumption, as it were, once MFA stood completely destructed [1,2].

This scenario was virtually corroborated during the early part of the third stage of ATC, whe: in the US market, China swept some product segments that saw quotas being eliminated. So much so that the US government prompted, by a campaign from major industry associations, clamped 3 safeguards in late 2003 [3]. Ever since, taking advantage of an election year, US industry interests have been stepping up the campaign to place more intensive as well as extensive curbs on China. The current year has also seen a global coalition emerge, *uniting* 92 industry associations in 54 textile and clothing importing, and exporting nations too (for the first time in the history of this trade!) to raise the Istanbul Declaration calling for the extension of the ATC [4]. Encouraged by this, Mauritius, Bangladesh and a few other countries moved the WTO to defer by three years the complete elimination of the quota regime [5]. Fortunately, the move was not supported in the WTO; besides, USA and EU have reiterated that they stand committed to the removal of quotas and to the return of textile and clothing trade to GATT principles. But, that, in no way, has diminished the shrill notes on the danger posed by China to the rest of the global exporting community.

Industry voices in India have also sung a similar refrain, although there has been little supportive evidence present in their lyric. Nevertheless, there has been an abiding anxiety and, therefore, it is time that this anxiety is adequately addressed and mitigated, as it has become crystal clear that India does not face any threat from China.

In this paper, the evolving wisdom in and on the supply chain from a fresh body of research, has been narrated in section 2 and the likely impact of China on competing supplier nations, including India, has been prognosticated. In section 3, the paper proceeds to suggest a road map ahead for India to harness the opportunities in global markets. Section 4 brings the paper to a close with conclusions.

POST-ATC SCENARIO FOR INDIA

At the end of 2003, world trade in textiles and clothing registered USD 321.9 billion in FOB value, comprising USD 136.9 billion in textiles and USD 185.0 billion in clothing. Two years prior, global trade had stood at USD 279.2 billion. From 1995 to 2003, through nine years of the ATC, the index of import demand for textiles, clothing moved from 100 to 122, 148, respectively. During the first seven years, up to stage 2 of transition, the pace of growth of trade was slow, but picked up in the third stage. Table 1 summarises the interplay between 2000 and 2003 and the position of supplier countries on a global plane. *What emerges strikingly in textile trade is the spectacular gain by China, Turkey and less spectacular gains by India, Pakistan, and, surprisingly by EU, eroding, in their wake, USA, S. Korea, Taiwan and Japan. In clothing trade, spectacular gains were registered by China along with Turkey, EU, Bangladesh and Romania, and to a lesser extent by India, largely at the expense in shares of Hong Kong, Mexico, USA, Indonesia, S Korea, Chinese Taipeh and Thailand.*

Table 1. Top 10 Suppliers' Ranking and Share in Global Textile and Clothing Trade

Supplier	Textile				Clothing			
	2000		2003		2000		2003	
	Share (%)	Rank	Share (%)	Rank	Share (%)	Rank	Share (%)	Rank
China	12.8	2	19.7	1	21.8	1	28.1	1
EU-15	17.7	1	19.3	2	9.0	2	10.3	2
USA	8.7	5	8.0	3	5.4	5	3.0	7
S. Korea	10.1	3	7.4	4	-	-	-	-
Chinese Taipeh	9.3	4	6.8	5	-	-	-	-
India	4.6	7	4.8	6	3.4	7	3.5	7
Japan	5.6	6	4.7	7	-	-	-	-
Pakistan	3.6	8	4.2	8	-	-	-	-
Turkey	2.9	9	3.8	9	3.9	6	5.4	3
Indonesia	2.8	10	2.1	10	2.7	9	2.2	8
Hong Kong	-	-	-	-	6.0	3	4.4	4
Mexico	-	-	-	-	5.3	4	4.0	4
Bangladesh	-	-	-	-	-	-	2.0	10
Romania	-	-	-	-	-	-	2.2	8

Note- Only top 10 countries are featured in respective columns.

Source- Compiled from: (1) WTO, 2001, Background Statistical Information with respect to Trade in Textile & Clothing (G/L/474), Geneva; (2) WTO, 2004, Background Statistical Information with respect to Trade in Textile & Clothing (G/L/692), Geneva

Interestingly, China and Taiwan acceded to the WTO at the same time with similar conditions of treatment. In stage 3, of the 200 quotas cumulatively eliminated by Canada, EU and USA, nearly one-quarter of these had been incident on each of the two suppliers [6]. Yet, China scored a march over Taiwan, eating into the latter's trade share by virtue of cheaper labour costs and higher productivity. In a similar fashion, Hong Kong and S. Korea have yielded trade share to China.

Table 2 presents the scenario, highlighting the supply performance of India and China in the markets of Canada, EU-15, Japan and USA, which, between them, accounted for 63 percent of global imports in 2003. It is becomes evident that in the third stage of integration, up to 2003, India and China have performed well, the latter more impressively than the former largely on account of benefiting from elimination of 51 restrictions against it as compared with 9 incident on India.

Table 2

Year	Feat-ure	Item	Supplier							
			India				China			
			Importer				Importer			
			Canada	EU-15	USA	Japan	Canada	EU-15	USA	Japan
2001	Value	T	112.10	1772.03	1131.62	181.88	250.45	1834.20	1982.79	2135.27
		C	248.29	2377.65	2062.71	113.54	1091.07	8483.74	9275.16	14789.66
	AGR %	T	-3.68	-1.12	-6.44	4.82	1.82	-0.03	1.84	4.81
		C	1.04	4.47	-4.37	-18.72	11.07	3.69	3.93	0.51
	Rank	T	5	3	5	7	3	2	2	1
		C	4	6	11	8	1	1	1	1
	Share %	T	2.93	10.31	7.33	3.82	6.56	10.67	12.85	44.89
		C	6.32	4.92	3.90	0.59	25.95	17.28	13.97	77.08
2003	Value	T	146.19	1887.89	1527.90	175.55	379.89	2764.46	3627.50	2432.02
		C	303.75	3011.59	2308.68	95.47	1451.26	12363.94	12015.10	15579.32
	AGR %	T	10.16	16.19	12.55	-1.03	22.67	30.94	35.23	12.83
		C	14.51	18.93	4.06	10.16	16.83	26.48	19.17	13.26
	Rank	T	4	3	5	7	2	1	1	1
		C	3	6	7	8	1	1	1	1
	Share %	T	3.79	9.45	8.35	3.49	9.85	13.85	19.83	48.3
		C	6.75	4.99	3.24	0.49	32.24	20.47	16.86	79.66

Note- *Japan is the only non-retraining market; AGR annual growth rate; T- textiles; C- clothing*
Source- *As in Table 1*

Forecasts, based on simulation modeling undertaken in WTO, indicates that the maximum impact after quota elimination is likely to be occurring in the case of clothing exports to the USA/Canada, where it is anticipated that penetration will rise from 33.8 percent before elimination of quotas to 45.0 percent after elimination; by contrast in the EU, penetration of clothing exports may be expected to shift marginally from 48.5 percent to 51.0 percent. In the case of textiles, the before-after scenario will see upward shift of little consequence [7]. The anticipated shifts in country shares of exports of textiles and clothing to the EU and USA are shown in Table 3.

It transpires clearly that China and India stand to earn striking gains in their respective shares of clothing imports by EU and USA. Other countries, in contrast, face varying or mixed fortunes. This anticipated outcome is, indeed, plausible, for China and India have suffered the highest order of *export tax equivalent* during the quota regime [8]. In the USA, for instance, the incidence of export tax on China in textiles and clothing was 20 percent, 33 percent and that for India 9.8 percent, 34.2 percent, respectively. The same, in the EU, stood at 12 percent, 15 percent for China and 12 percent, 15.2 percent for India. Export tax equivalents incident on other suppliers, except, notably, Thailand, were considerably less severe. Thus, the elimination of quotas presents the largest conceivable incentive to both supplier countries in the restraining markets.

Quotas distorted comparative advantage in the first place. Further distortions were added through preferential treatment; the predicted decline in future trade shares of hitherto preferred countries amply demonstrates that the edifice of preferential trade has developed cracks in the third stage of the ATC and is set to collapse post-ATC [9].

Table 3. Forecast of Shifts in Trade Shares of Significant Clothing Suppliers Post- ATC

Supplier	Share in EU imports (%)				Share in USA imports (%)			
	Textile		Clothing		Textile		Clothing	
	B	A	B	A	B	A	B	A
China	10	12	18	29	11	18	16	50
Turkey	13	12	9	6	-	-	-	-
India	9	11	6	9	5	5	4	15
USA/Canada	9	7	-	-	-	-	-	-
Central & Eastern Europe	6	6	9	6	-	-	-	-
S. Korea	5	4	-	-	6	6	-	-
Indonesia	4	5	3	3	3	3	4	2
Chinese Taipeh	3	3	-	-	7	6	4	-
Africa	3	-	-	-	-	-	-	-
Other North Africa	3	3	6	5	--	-	-	-
Bangladesh	-	-	3	4	-	-	4	2
Hong Kong	-	-	6	6	6	5	9	6
Poland	-	-	5	4	-	-	-	-
Morocco	-	-	5	4	-	-	-	-
Europe	-	-	-	-	16	14	5	-
Mexico	-	-	-	-	13	11	10	3
Rest of America	-	-	-	-	10	8	16	5
Japan	-	-	-	-	3	3	-	-
Philippines	-	-	-	-	-	-	4	2
Sri Lanka	-	-	-	-	-	-	-	2
Rest of World	36	34	30	24	20	21	24	10

Note-B- before Elimination of quotas (base year 1997); A- after elimination of quotas (post- ATC); named suppliers in respective columns are prominent with respect to the column
Source- Compiled from Nordas, H.K., 2004, The Global Textile and Clothing Industry Post the Agreement on Textiles and Clothing, WTO, Geneva

Simulations are hazardous, virtual business, in that they are slave to assumptions, which are tested only with the passage of time. Trade is real business and it is the foresight and vision of masters in the supply chain that, indeed, throws better light on the dynamics of the future. Recent literature, taking into account the insights of leading businesspersons, underlines unequivocally that China and India are the favoured sourcing origins of importers and retailers in the developed markets in the post-ATC scenario. In 2003, a study, based on extensive interviews with diverse American textile and clothing interests, was carried out by the International Trade Commission of the USA. It concluded that *China would be the preferred source owing to its ability to produce at any quality level at a competitive price; nevertheless, business senses a risk in wholly depending upon China and, therefore, it is considered prudent to expand business in other low-cost supplying origins, particularly India, for its large manufacturing base to produce a wide range of textiles and clothing with low-cost skilled labour to add* [10]. The study anticipated that preferred suppliers would yield trade shares in the bargain. Much the same results emerged from another, independent, private study [11]. In late 2003, the European Commission issued an official communiqué to its members highlighting similar expectations [12].

At a Conference in New York organized by the World Trade Centre on the theme "Global Sourcing 2005", a top representative of J C Penney, a premier specialist retail corporation, echoed the same prognostication, in as many words. Market observers in India, especially equity analysts, have captured intelligence on the up scaled sourcing plans of several majors beneficial to India: "Walmart" to raise sourcing from USD 2 billion to USD 11 billion, or 5 percent of its global sourcing basket; "Gap" and "M&S" to substantially increase off take; "J C Penney" to increase purchases from USD 0.5 billion to USD 2 billion in 2 years; "Levis" to boost up outsourcing from India [13].

The underlying wisdom to these prognostications is that the erstwhile geographical dispersion of the supply chain, created by administered trade, is facing erasure from the map. As the ATC self-destructs on New Year's Day in 2005, and the remaining curbs in textile and clothing trade vanish into the blue, all nations, which survived in the international textile and clothing trade without revealed comparative advantage, are set to decline. The space vacated by them will be filled by China and India to a considerable extent and by a few other nations - notably Turkey, Pakistan, Sri Lanka, Bangladesh, Indonesia - to a lesser extent.

Thus, it is established that India faces no threat from China; it is apt to move on and ideate how India may harness its glorious opportunities.

INDIA'S ROADMAP

Very recently, an ICMF-sponsored study delineated a resurgent vision of India in 2010. It postulated that *textile and clothing exports could hit USD 40 billion from USD 11 billion in 2002 at an average annual growth rate of 18 percent. To harness this, the country needed to shift focus to value-added products, particularly in the apparel segment, through a well-*

designed strategy [14]. Thus, a turn towards this is much in order.

Tables 4,5 present manufacturing cost comparisons between several supplier countries that ship basic and fashion clothing to the US/Canada markets. In basic clothing, the countries that stand out are Madagascar, China, Kenya, India, Pakistan, Vietnam and Bangladesh in ascending order of unit cost incidence at landing. The same countries, in a slightly altered order, are joined by Indonesia and Sri Lanka as competitive fashion goods suppliers.

However, it could be misleading to think that business is driven purely by simple, arithmetical cost considerations based on the cheapest manufacturing cost, and, resultantly, on the landing cost propensity. Instead, a range of critical parameters have been identified as being paramount to sourcing decisions in the post-quota period; a comparison of some of the competitive countries along these parameters is illustrated in Table 6. It will be heartening to note that many considerations favour India as a logical sourcing base. However, there are a few other considerations, which must cause worry since the country is observed to fall short there: *service proficiency, plant size and industrial efficiency*.

Table 4. Comparison of Dollar Cost of Landed Basic Garments from Key Supplier Countries in US Market

Country	SAM Cost	Efficiency	CM Cost	Fabric Price	Freight	Import Duty	Total Cost
Madagascar	0.03	37%	0.79	2.05	0.1	0	4.66
China	0.04	65%	0.51	1.7	0.07	0.85	4.77
Kenya	0.03	42%	0.96	2.05	0.15	0	4.83
India	0.03	55%	0.49	1.85	0.07	0.85	4.95
Pakistan	0.03	47%	0.57	1.85	0.07	0.85	5.03
Vietnam	0.03	52%	0.52	1.95	0.07	0.85	5.17
Bangladesh	0.03	47%	0.52	2	0.07	0.85	5.17
Indonesia	0.04	55%	0.69	1.9	0.07	0.85	5.21
Honduras	0.09	57%	1.42	2.1	0.07	0	5.35
Mauritius	0.1	60%	1.5	2.05	0.1	0	5.37
Sri Lanka	0.05	52%	0.78	2	0.06	0.85	5.43
Mexico	0.13	62%	1.89	2.1	0.03	0	5.82
Aggregate	**0.05**	**53%**	**0.89**	**1.97**	**0.93**	**0.50**	**5.14**

Source- Table 9 (based on KSA estimates) in Bothra, S., 2004, Indian Textile & Apparel Industry, Alchemy, Mumbai

Table 5. Comparison of Dollar Cost of Landed Fashion Garments from Key Supplier Countries in US Market

Country	SAM Cost	Efficiency	CM Cost	Fabric Price	Freight	Import Duty	Total Cost
China	0.04	65%	1.02	1.7	0.07	1	5.43
Madagascar	0.03	37%	1.58	2.05	0.1	0	5.45
India	0.03	55%	0.98	1.85	0.07	1	5.59
Pakistan	0.03	47%	1.15	1.85	0.07	1	5.75
Vietnam	0.03	52%	1.04	1.95	0.07	1	5.77
Kenya	0.03	42%	1.93	2.05	0.15	0	5.79
Bangladesh	0.03	47%	1.03	2	0.07	1	5.83
Indonesia	0.04	55%	1.37	1.9	0.07	1	6.04
Sri Lanka	0.05	52%	1.56	2	0.06	1	6.36
Honduras	0.09	57%	2.84	2.1	0.07	0	6.77
Mauritius	0.1	60%	3	2.05	0.1	0	6.87
Mexico	0.13	62%	1.77	2.1	0.03	0	7.7
Aggregate	**0.05**	**53%**	**1.77**	**1.97**	**0.93**	**0.58**	**5.14**

Source- as in table above

Table 6. Global Retailers' Assessment of Major Supplying Countries

Parameter	Turkey	Vietnam	China	Kenya	India	Sri Lanka	UAE	Mexico
Labor Skill	◈	O	◈	×	◈	◈	◈	◈
Service	◈	×	◈	×	O	◈	◈	◈
Flexibility	◈	×	×	×	◈	◈	◈	◈
Capacities	O	◈	◈	O	O	◈	◈	◈
Textile Sector Banking	◈	×	◈	×	◈	×	×	O
CMT Costing	O	◈	◈	◈	◈	O	×	×
Avg. Industry Efficiency	×	×	O	×	×	O	◈	◈
Avg. Working Hrs/ Week	◈	O	◈	◈	◈	◈	◈	◈
Fashion	◈	×	×	×	◈	◈	◈	◈
Logistics	◈	◈	×	×	◈	◈	◈	◈
Political	◈	×	◈	×	◈	◈	◈	×

◈ **Good** **O Average** **× Bad**

***Source-** as in Table 4*

Years ago, how service proficiency will determine prospects of survival for clothing suppliers in the post-quota future was already postulated [15]. Indian exporters are assessed to be notorious for poor managerial and transactive efficiency, which translates into a high order of cost, disproportionate to the sourcing intensity, for importers. This continues to prevail owing to cultural traits, and, unless overcome early and deliberately, may have foreboding consequences in the time to come. The policy framework of the past ensured uneconomical plant size that, however, was not at all forbidding, because the export incentives compensated generously in substitution [16]. The WTO regime has practically dismantled this largesse. Fortunately, better wisdom is implicit in the policy dispensation of recent years, catalyzing exporters to augment plant size by consolidating multiple plants into single or fewer, more ably manageable, facilities. Poor industrial efficiency is endemic to the Indian industrial environment, mainly generated by deficiency in power supply. Government cannot escape its crucial responsibility here; there is, of course, the concerted move to establish textile and apparel parks with uninterrupted facilities, but the pace of progress leaves much to be desired. Furthermore, there appears to be a lack of strategic focus in this area of support to industry. Additionally, lack of modern management systems drives down efficiency in manufacture.

The above supply side features must also balance with the demand side ones. Indeed, this is likely to prove even more critical. India has developed demonstrated competitiveness in 5 items of clothing: women's dresses/suits; men's woven shirts; women's woven blouses; T-shirts; knitted shirts. The world's most exported products are: jerseys (USD 17 bill.); men's trousers (USD 13 bill.); T-shirts (USD 11 bill.); women's trousers (USD 9 bill.); men's shirts (USD 7 bill.); women's dresses and skirts (USD 6 bill.); women's blouses (USD 5 bill.); overcoats (USD 5 bill.); underwear (USD 5 bill.); and jackets (USD 4 bill.). It is very obvious that the country demonstrates sizable presence in only half the number of highly demanded and valuable items. India's share in global exports of these items of clothing is approximately 16 percent each for women's dresses/skirts and men's shirts, 13 percent for blouses and 5 percent for T-shirts.

In all these product segments, there are basic as well as fashion goods; it is estimated that basic goods account for 60-70 percent volume and only 30 percent value, with fashion goods making up the rest. Fashion is definitely on the rise, what with the trend towards smaller order sizes, an area in which China is not a patch on India. India is recognized for fashion production and it is utmost pragmatic to continue in this image, given both supply-side and demand-side propensities. However, that does not imply that basic goods must be ignored; since there are strong capabilities here, too, they must be encouraged. Indeed the country divides itself neatly into a geography, in which fashion production dominates the north and basics the south.

With respect to products of competence, there will be the obvious surmise that the shares will go up considerably in the post-quota scenario; but it could also be stretched, since, for instance, in the US market, in some segments, during the quota regime itself, imports have nearly matched with or surpassed quantitative domestic demand [17]. Notable in this respect are shirts, blouses and T-shirts. In such a scenario, the pressure in the short run will be to upscale product on the value scale in diverse ways suiting market preferences. For some time, the prevailing volume strategy may prevail for women's dresses/skirts, as the US market is not yet, reportedly, saturated with imports. In all product segments following volume strategy, the thrust should be on productivity enhancement.

India stands a good chance to diversify to new product segments and to markets other than the restraining countries. In the short run itself, diversification to man-made fibre clothing is highly desirable, given the current impressive growth rates and the country's fibre production capacity. Exporters will have to diversify to other lucrative product segments, such as jerseys, men's and women's trousers, overcoats, underwear and jackets. These products demand fabric as well as garmenting strengths, and there is no reason why the Indian supply chain should not be able to make profitable business out of them, given the massive investments in technology that have taken place of late in the critical stages of the supply chain, coupled with the prevailing implicit fiscal incentive for vertically integrated manufacture. Vertically integrated manufacturers will find this avenue very remunerative and it should not be out of their reach to succeed in the short run itself. Successful penetration implies that other business investment than the manufacturing will have to be made, particularly in new markets; it will make sense to diversify first to existing markets, where considerable business investment already exists, before attempting the same in new markets. Table 7 composes the above in a product-market matrix frame, taking after Ansoff[18].

Table 7 - Strategy Matrix for India's Clothing Exports

Products	Term	Markets		
		Existing		**New**
		Value Driven	Volume Driven	
Existing	Short	* Men's Shirts * Women's Blouses *T-Shirts	*Dresses/ Skirts	
	Medium/Long	*Dresses/ Skirts		*Men's Shirts, *Women's Blouses, *T-Shirts, *Dresses/ Skirts
New	Short		*Men's Trousers, *Women's Trousers, *Overcoats (integrated producer-exporters)	
	Medium/Long		* as above *Under-wears *Jerseys, (non-integrated producer-exporters)	*Men's Trousers *Women's Trousers *Overcoats, *Underwear *Jerseys (all producer-exporters)

Source- *Authors*

CONCLUSION

The post-ATC scenario holds the following distinct plausibility:

a. Global trade in textiles and clothing, while returning to GATT, will eliminate hitherto prevalent trade distortions and operate on principles of comparative advantage.

b. Supplier countries with large manufacturing base and supply chain extending from fibres to designing will emerge as principal gainers: China, India and Turkey will belong to this club.
c. Countries with less extensive manufacturing base and supply chain compensated by proximity to a stronger county in this respect, will also gain, although marginally, when compared with the big 3 above. Bangladesh, Sri Lanka, Pakistan, Indonesia will benefit.
d. Countries that prospered in exports to retraining countries by dint of preferential treatment under the Outward Processing Programme will lose their standing in trade. This goes for most East European, North African, Caribbean Basin suppliers, save Mexico, which, although diminished in trade share, will continue to count as a supplier.
e. Similar fate as above awaits those countries which grew in trade owing to the preferential treatment emanating from FTA agreements, such as beneficiaries of Cotonou Declaration, AGOA, Andes Pact, CIBERA, most of which qualify as LDCs.
f. The rise of the future big 3 implies the erosion of trade shares of other countries; thus, it is not China alone that threatens the most likely to lose out, so do India and Turkey, too.
g. There is no inter-se threat to one another from among the big 3.
h. While importers will continue to be driven by low labour cost considerations, that will not be at the expense of service levels, manufacturing proficiency and industrial efficiency.
i. To seize the opportunities coming its way, India must continue to play its dominant role as supplier of fashion goods, but also make strong inroads into basic goods to capitalize on its vertically integrated infrastructure and the intensive technological investments into the same made from TUF.
j. In the short run, India may pursue an intensive approach by deepening its share of trade in items of clothing in those markets where its competitive strength is intact. In the medium run, India must diversify to new products to sell in existing markets. In the long run, both existing and new products may be exported to new markets.

What is the time frame that spells the short, medium and long runs? That is logically set by an externality, namely the provision for safeguards to be levied on China by WTO members: up to 4 years (2005-2008) in textiles and up to 8 years (2005-2012) in clothing. Known for their pragmatism, the Chinese will grow fast enough only to stop short of inviting safeguards. Thus, there will be, for a long time, a forced dampener acting on China's so-called limitless prospects. This is a god-sent time-line during which India should go full steam ahead and even surpass the WTO-estimated expansion.

Acknowledgement

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A Complete Personalised Visualisation Apparel System Incorporating Novel Fabric Measurement

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The rapid emergence of the Internet provides the required techno-infrastructure for the global retailing realization. Many companies have capitalized on this provision and have used it in many diverse ways, from electronic mailing to marketing, selling and trading of products and services. The fashion industry, however, has only experienced minor benefits from this growth. Major problems are the lack of relatively simple way to use customer information to display accurate 3D vision quality of the product. This paper presents an set of effective solutions using a complete visualization apparel system to display a real time virtual wearer trial on fully skinned individual virtual human with life-like feature appearance and garment drape behavior, using ordinary photographs from customers and fabrics data from a database connected with the Internet. A much simple fabric measurement system is also incorporated into this system. The approach is based on the new results of the four research area: reconstruction of the human body based on parametric hierarchical mesh with new digital cloning algorithm of human feature detail, animation skeleton from ordinary photographs, physical-based cloth modelling, database and internet connection, and fabric measurements, funded by the European Union, Scottish Enterprise Borders and industries.

In recent years we have witnessed a revolution in networking of information on a global scale via the Internet. The new philosophy of 21st century will be based upon global **retailing** living without frontiers [1, 2]. Research can now provide the required techno-infrastructure for the realization, which will force restructuring of the industries, and provide new possibility in consumer buying methods and new opportunities in the supply chain. It will enable **customers** to design and to purchase garments for **their specific requirements by conducting virtual wearer trials using their own body size and shape to try the garments on.**

The strategic formula for competition has to be the development of own technology, its effective use and innovation for new products. It is the only way that will enable companies to be fit for survival, profit and growth in the new century. Our synthetically human model is based on a parametric hierarchical multi-resolution mesh from Bicubic Spline and Trigonometry functions; supplemented with individual model fitting, the system can deform the mesh's shape and size into an individual model with real human data which can be generated from customer's photographs. The face characteristics can be reconstructed by the digital cloning technique developed in the system. This is the basic requirement for modelling the movement of garment as it is being worn by the virtual human, since this model is required by fabric draping as constraint to the garment, and also, to provide an personalised character with a real appearance in virtual wearer trials. The key techniques concerning this requirement in our work are: the geometrical reconstruction, the digital cloning of human features, the body animation of real humans, the cloth simulation and the automatic measurement of fabric mechanics as well as database and internet. In this paper, we describe a successful integration of these techniques using customer's photographs and fabrics data from a database connected with the Internet. The approach emphasises simplicity, low-cost and accessibility by anybody without special equipment. We recognise the potential application of such a system in many industrial applications.

THE RECONSTRUCTION OF VIRTUAL HUMAN

Geometrical Model

The inspiration of the current reconstruction algorithm arouses from that geometrical **shape of** the human silhouette is topologically equivalent to ellipse cylindrical surfaces and is geometrically symmetrical around its center line. Accordingly, the initial mesh sufficiently represents the desired silhouette shape of the human object from the limited of feature points that can be measured by an image processing with **mouse** coordinate anchor functionality. The **further level** details of **the** hierarchical multi-resolution **mesh** of the **object** are added with trigonometry and Bicubic Spline incorporation functions [3] on and between cross sections separately. The surface patches based on these 3D curves is represented by

$$Q(t,s) = \sum_{i=0}^{n} \sum_{j=0}^{m} B_{i,j}(t,s) P_{i,j}$$

Where, $P_{i,j}$ is an array of control points and $B_{i,j}(t, s)$ is a basis function evaluated by

$$B_{i,j}(t,s) = B_i(t) \cdot B_j(s)$$

Where, $B_i(t)$ and $B_j(s)$ are defined as Bicubic Spline or Hermite [4] and Trigonometry functions in the reconstruction.

Figure 1 illustrates an application example for the reconstruction algorithm in the human head silhouette. The head has a slightly flat surface in the front relative to its other parts. Generally, the transition always occurs nearby the outside extremity line at both of left eye and right eye due to a big change of the curvature of the geometric surface nearby these lines. Thus an algorithm for calculating vertex coordinates on these cross sections of the front semi-head is **designed.**

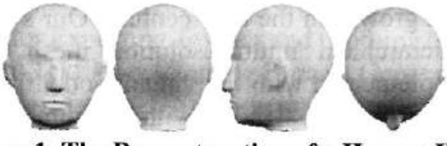


Figure 1. The Reconstruction of a Human Head

Let headfront [k][m], headside [k][m] and headback [k][m] (m = 0, 1, 2) stand for the original vertices on the primary cross sections from the outline curves in the front, the side and the back views, respectively. The vertex coordinates on these primary cross sections of the front semi-head are determined by:

$$Vertex[i][j][0] = headside[k][0](1 + a * fabs(\sin(\frac{j}{po\,\text{int}} * 2\pi))) * \cos(\frac{j}{po\,\text{int}} * \pi)$$

$$Vertex[i][j][1] = headside[k][1]$$

$$Vertex[i][j][2] = headfront[k][2](1 + b * fabs(\sin(\frac{j}{po\,\text{int}} * 2\pi))) * \sin(\frac{j}{po\,\text{int}} * \pi)$$

(k = 0, 1, 2, …, keyframe-1; i = 6*k; j = 0, 1, 2,…, point-1)

Where, a, b is feature constant; j/point and j2/point are separately represented as coincidence angle to calculate its trigonometry function values for determining the vertices and its coefficient in a circuitry periodicity of the front semi-head on i^{th} level cross section. Similar algorithm may be used to reconstruct the remainder of the head in other views.

Modification to the silhouette of the human object begins by specifying the geometrical shape of a hierarchical multi-resolution control mesh in terms of position variation of a few feature control points. **More** detailed shape feature, especially for a realistic head, can be supplemented by manipulating a localized deformation nearby the feature points or curves on the parametric surface based on the integration of the line deformation algorithm, in combination with appearance feature measurement and a curve-fitting algorithm presented in our work. As a result, a generic parametric model can be deformed into any specific human model with regular vertex distribution.

Digital Cloning of Human Features

With regard to the generation of the texture image, the texture coordinate of each vertex on the mesh of the head is calculated by varying the plane texture mapping algorithm on the different (x, y, z) region of the model mesh. Guided by the merging lines for the texture image, all vertices of an individualised 3D head surface are projected onto one of the following three planes: YZ plane on the left view, XY plane on the front view and YZ plane on the right view. And then the point on the 3D head is projected to the corresponding region of the 2D texture image and finally the mapping coordinate of the points on a texture image is generated. If we take one point on the front face as (X_i, Y_i, Z_i) on 3D head model, we can compute the 2D related texture mapping co-ordinate in the texture space by following

$$u_{ij} = (X_{ij} - H^{i}_{\min}) / (H^{i}_{\max} - H^{i}_{\min})$$

$$v_{ij} = (Y_{ij} - V^{j}_{\min}) / (V^{j}_{\max} - V^{j}_{\min})$$

(i = 0, 1, …, level-1; j = 0, 1, …, point-1)

where, $(H^{i}_{min}, V^{j}_{min})$ and $(H^{i}_{man}, V^{j}_{man})$ stand for the minimum and maximum of unfold value along i^{th} horizontal and j^{th} vertical direction on **the** head model surface respectively. Similarly, instead of X_{ij} with Z_{ij}, the formula can be used to calculate the texture mapping coordinate for one point on the side of the head.:

Figure 2 shows an example of feature cloning of the human head from the photographs of a real person, which proves that the cloning algorithm can produce an individualized human head with more realistic complexion and tint to provide the character a real appearance.

Figure 2. Reconstruction Process of a Real Head

Skeletal Motion

In order to model a synthetic human, a skeleton model was firstly developed, which can be regarded as a special linkage system. There are a number of body modelling research of complex cases reported [5, 6, 7], in which the researchers try to model complex body movements precisely and efficiently. For this study, the ultimate aim is to incorporate the dynamic behaviour of the fabric drape; therefore a relatively simple human animation model may be adequate. At the current stage, our synthetic human model is able to complete a number of basic body movements, like walking and running. Fourteen individual bones are reconstructed separately and then connected to each other at pivots to construct the animated body model. The skeleton movement is calculated using the joint angles and its reference joint points. After the creation of a frame loop in each step of the cycle, the transformation created at each joint starts from the root of the hierarchy linkage, passing down the transformation of the parents to their children through linking the passed down translation vector and the local translation matrix. Flexible skin deformation with body movement is based on vertex blending or skinning smoothness algorithm [8]. An example of the animation procedure of a character skeleton is shown in Figure 3, which displays a lifelike human walking animation cycle with seamless connection.

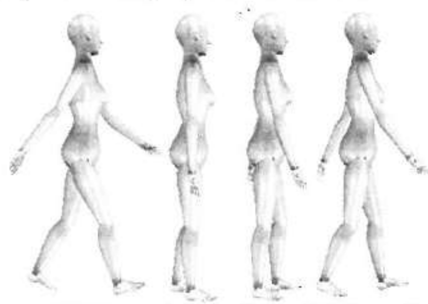


Figure 3. Human Walking Animation with Seamless Connection

AUTOMATIC MEASUREMENT OF FABRIC MECHANICS

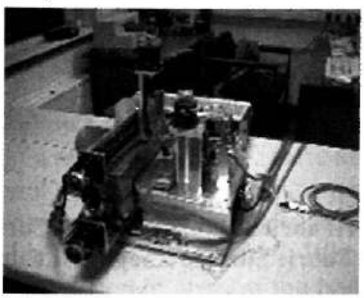
Textile materials are engineering structures that do not behave as solids nor as liquids, i.e. they are said to be limp and they possess visco-elastic properties which enable them to take up any 3D configurations by wrapping or hanging around solid bodies. An added interest is that textile structures are diverse and they are made of different raw materials and designs. By implication therefore there are a high number of those materials which need to be defined as engineering structures for reasons of design and manufacture, quality and performance, but most importantly, in our case, for realistic garment drape during modelling and animation. This need can be satisfied by measuring their mechanical properties, which can be identified as tensile and bending, shear, compression and surface roughness. FAMOUS is a new concept of textile measurement and this section describes the equipment and its use in textiles, clothing and retailing [9].

After extensive scientific and industrial use over the last twenty years, the general understanding about the current provision of equipment is that the KESF is regarded as a scientific device for research and FAST as a simplified alternative devise for industrial use. Both instruments offer mechanical measurements but they have shortcomings which hinder the use of them widely, especially in the modelling and animation fields [10-12].

Recently, under the pressure of the community a new concept was established which was developed into a new devise for measurement of fabrics. This devise is called FAMOUS; and stands for fabric automatic measurement and optimization universal system. In the new equipment for simplicity, all tests had to be made using one sample only and without the need for human intervention. Therefore a new concept of measurement in two planes had to be invented: one for tensile, shear and flexural rigidity and another for thickness, compression and surface.

The first aim of this instrument is to provide a single apparatus for the measurement of the mechanical properties of a single fabric sample in order to reduce the equipment costs compared with that of the number of existing devises. The second aim is to reduce the time and complexity of making such measurements and to increase accuracy and reproducibility compared with the existing methods, whilst enabling compatibility of magnitudes with the existing equipment.

Figure 4 **a)** shows a photograph of the equipment, which is "all in one", bench top and portable. A fabric sample is cut 20x20 cm and placed on the machine. All magnitudes and measured parameters are compatible with those of existing equipment so that there is direct correlation and continuation of measured data, with the exception of flexural rigidity which is being derived by a different mode of measurement. A complete suite of measurement takes less than 5 minutes and the measured data is interpreted into a Fabric Data Chart automatically as shown in Figure **4 b)**



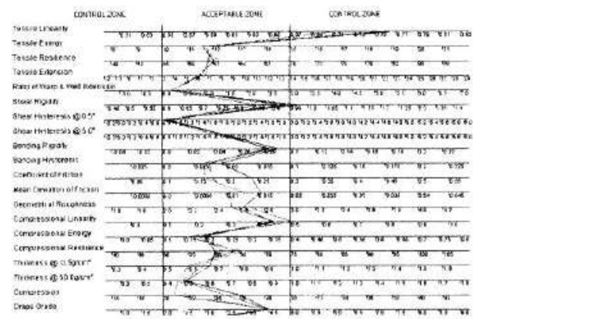
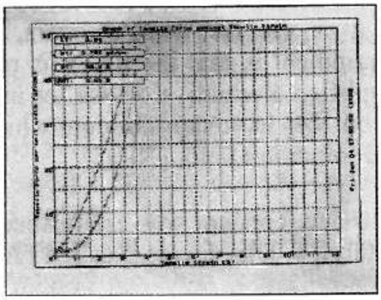
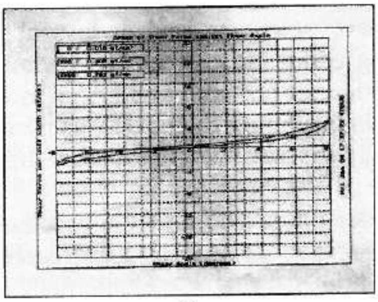


Figure 4. a) The FAMOUS Equipment; b) Automatically Produced Fabric Data Chart

Figures 5 show various typical mechanical property curves of a wool worsted cloth produced by the equipment. It includes a tensile cure; a shear hysteretic curve; a flexural rigidity curve; a thickness and compression curve and a surface roughness curve. These curves provide an accurate measurement of the particular mode of deformation that the fabric sample is subjected to, so that the prediction of the behaviour of the material can be established.



a)



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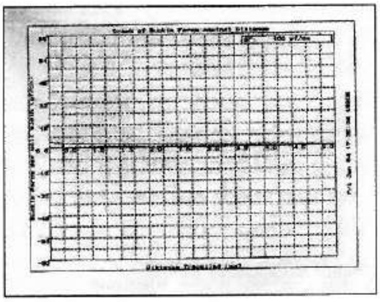

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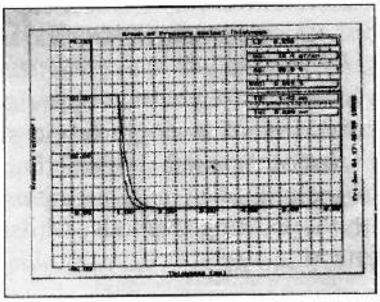

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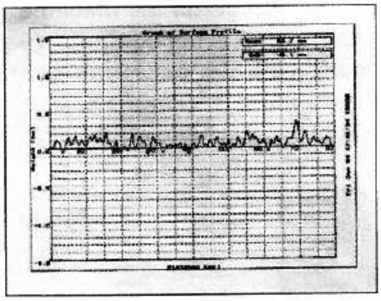

e)

Figure 5. Various Typical Mechanical Property Curves
a) Fabric Tensile Curve; b) Fabric Shear Curve; c)Fabric Flexural Rigidity Curve; d) Fabric Thickness and Compression Curve; e) Fabric Surface Roughness Curve

FABRIC DRAPING MODEL AND A VIRTUAL WEARER TRIAL

The drape model used in the virtual system is based on a mass-spring system [13, 14]. The deformation of fabric follows the laws of physics. The constraints used in the process are the forces due to gravity and collision, which are calculated and integrated to move each node of the fabric model. The fundamental equations of Newtonian dynamics can be integrated over time by an Euler method:

$$\upsilon(t+\Delta t) = \upsilon(t) + \frac{F(t)}{m} * \Delta t \qquad x(t+\Delta t) = x(t) + \Delta\upsilon(t+\Delta t) * \Delta t$$

Where, Ät is the chosen time step. More complicated integration methods, such as Runge-Kutta [15], can be applied to solve the Newtonian dynamics differential equations.
The final global drape governing equations can be written as a general form:

$$\tilde{M}\ddot{x} + \tilde{C}\dot{x} + \tilde{K}x = F$$

where, , andare: the mass matrix, the damping matrix and the stiffness matrix respectively. is the distributed external force vector applied to each node.

In order to evaluate the drape behaviour of the fabric system developed in the current work, an experiment was carried out in which two materials were selected. By using different setting for the parameters, the draping behaviour of different kinds of fabric can be simulated. Figure **6** shows the simulation of two different fabrics (the right one is lighter and more elastic than the left one).

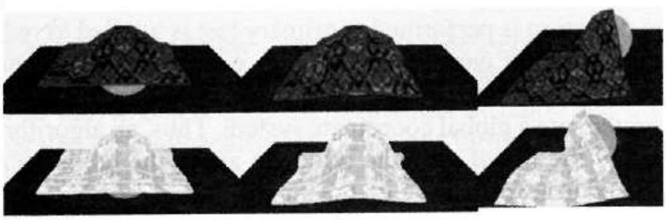

Figure.6. Drape Behaviour of Two Different Fabric Types

In order to evaluate the drape behaviour of the fabric system developed in the current work, an experiment was carried out in which two materials were selected. By using different setting for the parameters, the draping behaviour of different kinds of fabric can be simulated. Figure ε shows the simulation of two different fabrics (the lower one is lighter and more elastic than the upper one).

Figure **7** shows two examples of virtual wearer trials on a real female model, with digital cloning of a real human and a fabric texture. The resultant shape of the garment is determined by material mechanical properties measured by FAMOUS, body shape and the defined garment design pattern. Garment animation is performed by handling the collision between the cloth and a moving body model. When the cloned human is moving, collisions between the garment and different parts of the body are detected and repulsive forces are calculated and applied.

The collision detection is based on computing the distance between each node of the garment and a series of spheres or cylinders arranged as the character's animation hierarchy that vary as the skeletal bones of the character to be dressed move. If the distance is less than a certain threshold, there may be an intersection in the location. When further penetration into the surface occurs, a penalty force by Newton's Law is applied along the normal direction of the surface to move mass points away from the surface. The magnitude of the acceleration is proportional to the negated distance between the cloth node and the surface, and the direction will be vertical to the surface. The penalty force returned is added to the total force applied to the garment node in order to modify the movement of the node for the following time frames of the simulation, which avoids intersection with the skin.

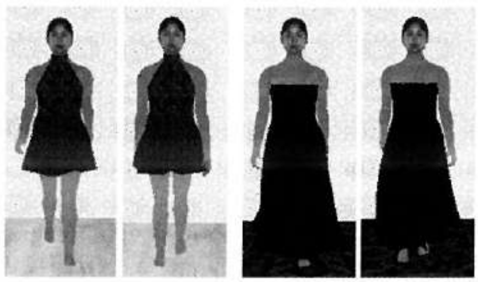

Figure 7. Virtual Wearer Trials on a Real Female Model

Before this collision detection is performed, a primary test is applied to reduce the number of collision that the nodes of the garment make with each segment of the body. Since the reconstruction of each segment of the body is based on animation skeletal bone, the position of the skin can be integrated into a global coordinate system. Thus, an algorithm may be designed to find out dynamically the list of garment nodes to apply the collision detection for each segment to be considered in accordance with the range of the X- and Y- coordinates of the skin vertex of the segment. Meanwhile, the nodes of the garment model nearby the border between subdivisions belong to both of the segments.

Database System via Interactive Internet

We propose a system that performs clothing simulation on an individual body model, as shown in Figure 8. The presented architecture corresponds to an integration of reconstructing, cloning and animating of virtual humans as well cloth simulation. A much simple fabric measurement system is also incorporated into this system to provide material mechanical properties of the modeled fabric. The database connected to Internet provides the necessary platform to track all project related information and potential application intelligence via the Internet for the virtual human reconstruction and virtual wearer trial.

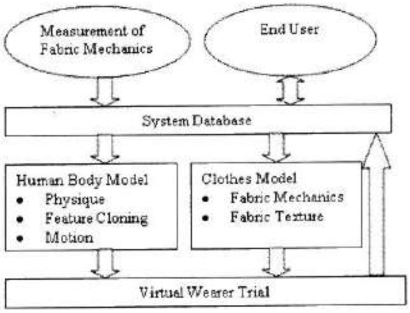

Figure 8. Online Virtual Wearer Trial System

In this system, the Microsoft SQL server was used to create and configure the relational database. The database with image-based retrieval capability connected with the Internet is designed to provide the programmer with customer photographs for the reconstruction and digital cloning of feature details. In addition, the database is being designed to search the desired color, knitted or woven designs and different types of fabric for the garments to be dressed, including their mechanical data. Finally, the results of a virtual human reconstruction are stored in the database and can be feedback to customers.

CONCLUSIONS

In this paper, various independently computer technologies, including the geometrical reconstruction, **the** digital cloning of feature details, the body animation of **a virtual human, the measurement of fabric mechanics,** the simulation of fabric and their development are presented and integrated for realistically simulating of a virtual wearer trial. The fabric model reported is capable of simulating various textile materials. The resultant examples have highlighted many possibilities not only for virtual retailing of textiles, but also for potential tools used in CAD, in virtual environments, in entertainment industries.

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Soft Computing In Textiles: A Study Of Fabric Drape Prediction Using Neural Network

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Many textile material characteristics have nonlinear response and modeling the behavior of such materials involves dealing with multiple variables and parameters. Conventional analytical techniques are very difficult to use to understand the behavior of many textile materials and systems. One of the techniques that can be employed in modeling a nonlinear, multivariate and imprecise system is the use of soft computing. Employing techniques such as fuzzy logic, neural networks, machine learning and probabilistic reasoning, either solely or in combinations, soft computing gives low cost and robust solutions. This paper describes the use of soft computing in predicting the drape of fabrics which depend on several different characteristics of fibers, yarns and cloth structure. Neural networks are used to predict the drape coefficient and circularity of many different types of fabrics. The multilayer perceptron using backpropagation and the radial basis function neural networks were used. The backpropagation method was found to be more effective than the radial basis function but the latter was faster when it came to training. Comparisons of the two models as well as the effect of using different parameters on the same model are presented. Also, the results of neural network analysis show that the prediction of fabric drape coefficient was more accurate than that of the circularity of drape.

Drape is the most important of fabric properties for the apparel textile industry and some industrial textile applications. This unique fabric property is very complex and it is very beneficial to predict the drape of fabric for computer aided design and manufacturing. Drape prediction can reduce the need for fabric sample production and thus speed up the process of designing new fabrics. As a result of this, production cost will decrease and production time will shrink. Predicting drape is one of the key steps for the textile industry to move one step forward. Therefore drape prediction has been one of the biggest challenges to the textile industry for many years. Many scientists have been trying to predict how fabric drapes over rigid surfaces, using both empirical and other methods. In this study, we use neural networks as a tool to predict the drape of fabric from measured fabric mechanical and physical properties because there does not exist an empirical relation that relates drape to these properties. Supervised artificial neural networks are able to handle many variables as inputs and form a relationship between the inputs and the output from experience. Since these systems are capable of automatically constructing correlation between known cause and effect situations, they can be very useful for predicting the fabric drape coefficient. Continuing the work of Gocke [6], the performance of backpropagation (BP) and radial basis function neural networks (RBF) are investigated.

FABRIC DRAPE

A Drape Coefficient and Circularity

The drape coefficient (DC) and circularity (CIR) in this study are values that are obtained from measurements of the fabric drape image acquired using a Cusick Drape meter [3] as illustrated in Fig. 1.

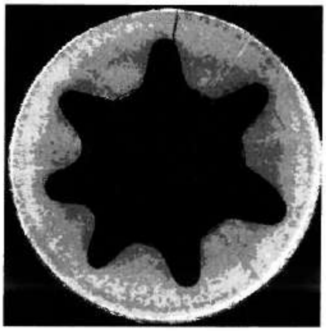


Fig. 1. Specimen draped over a pedestal with a light source beneath it.

DC and CIR are defined by the following equations:

$$DC = 100\left(\frac{A_d - A_c}{A_o - A_c}\right) \qquad (1)$$

where A_d is the area inside the drape curve, A_c is the area of the inner circle, and A_o is the area of the undraped fabric as can be seen in Fig. 1.

$$CIR = 4\pi\left(\frac{A_d}{P^2}\right) \qquad (2)$$

where P is the perimeter of the drape curve.

Digital image analysis algorithms were written to calculate these two values from all the images acquired for the fabrics used for constructing the training and testing sets.

Parameters for Prediction

It was found in the literature on fabric drape that various factors influence drape. Chan and Hu [2] found that bending rigidity, hysteresis of bending moment, shear rigidity, hysteresis of shear force at 0.5 degrees, hysteresis of shear force at 5 degree, fabric weight, mean deviation of friction from the surface roughness test, and linearity of load-extension curve are highly correlated with the drape coefficient. Frydrych, Dziworska, and Cieslinska [4] also reported that bending rigidity, initial tensile modulus, weave, weight, and tensile recovery affect the drape of fabric.

Amirbayat and Hearle [1] made a theoretical investigation on the draping behavior of sheet materials and they found that the geometric form of deformation can be related to two dimensionless energy groups, relating bending, membrane, and potential energies, and definable in terms of sheet parameters and size. The two dimensionless energy groups J_1 and J_2 relate membrane strain energy Um and potential energy U_p to bending strain energy U_B by $J_1 = U_m / U_B 2$ and $J_2 = U_p / U_B$, where is a geometrical measure of the form of deformation. In terms of material properties, $J_1 = Y l^2 / B$ and $J_2 = \tilde{a}\ g\ l\ 3 / B$, where B is the bending stiffness, ã g is fabric weight, Y is the fabric membrane modulus, and l is the characteristic length defining the size of the material. Their experiment showed that drape coefficient is not only a function of J_1 and J_2, but must also be influenced by other parameters such as the full set of anisotropic in-plane membrane and out-of-plane bending and cross-term elastic constants, and perhaps the nonlinearity of response.

Niwa and Morooka [9] also investigated relation between drape coefficient and mechanical properties of fabrics and showed that bending rigidity (B: g cm^2 / cm) and weight per unit area of fabric (W : g/cm^2) are most determinative parameters to the drape of fabric.

In addition, Gaucher et al. [5] studied warp and weft knitted fabrics and reported that bending length, weight, thickness, and shear modulus are best predictors of drape coefficient of knitted fabrics.

To predict DC and CIR, seven parameters were chosen to be the neural network inputs. The seven parameters are weight, thickness, bending rigidity, shear rigidity, hysteresis of shear force at 0.5 degrees, linearity of load-extension curve, and weave. These seven parameters are chosen out of thirteen measured properties because the literature has shown these parameters to influence the drape of a fabric the most.

DATA COLLECTION AND PROCESSING

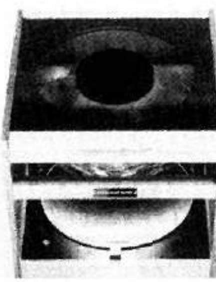


Fig. 2. Cusick Drape Meter

The Kawabata test instruments were used for testing thirteen mechanical properties of the fabrics, a thickness gauge to test the thickness, and an electronic scale to weight of the fabrics. The DCs of the fabrics were calculated by using a Cusick drape meter as seen in Figure 2. At the same time, digital images of the draped fabrics were also captured. For digital image capturing purposes, a digital camera was mounted 60 cm. above from the top panel of the Cusick drape meter. Images of draped fabric captured using the Cusick drape meter were saved in PGM file format to avoid any loss of data due to compression. Programs for digital image analysis were written to analyze the images and determine the DC and CIR of the draped fabrics. Long and Robson [8] reported that there is very high correlation between the drape coefficient values measured by image analysis and drapemeter measurement. It was decided that the digital image analysis method provides more accurate results because it eliminates human error from manual measurements.

METHODOLOGY

Backpropagation

Backpropagation is typically done on feed forward neural networks are able to generalize well on a wide variety of problems. These training methods are called supervised training because they are trained with both inputs and outputs. Input signals propagate through the network layer by layer, in the end producing a response at the output of the network. This phase of the operation of back-propagation is called the forward phase. The output of the network is compared with the target response, generating error signals. These error signals propagate in a backward direction through the network. In this phase, the weights of the network are adjusted to minimize the sum of squared errors:

$$E = \frac{1}{2}\sum_i (t_i - y_i)^2 \qquad (3)$$

Where t_i is the *i*th desired output (target) and y_i is the *i*th output.
The equation for each delta weight$_{ij}$ at the *l*th iteration is:

$$\Delta w_{ij}(l) = \mu_i \delta_i y_i + m\Delta w_{ij}(l-1) \qquad (4)$$

Where μ_j is the learning rate, y_j is the *j*th output from the previous layer, m is the momentum constant (momentum can help the network from getting "stuck" in local minima when training), $\Delta w_{ij}(l\text{-}1)$ is just the previous weight change made, and δ_i is defined as:

In the case of our linear output layer:

$$\delta_i = t_i - y_i \qquad (5)$$

In the case of the hidden layer:

$$\delta_i = f_i^{'}(net_j)\sum_{k \in P_j} \delta_k w_{ki} \qquad (6)$$

The δ_k and w_{ki} in (6) are from the layer above the layer for δ_i. (P_j is the set of posterior neurons.) f is the activation function of the particular neuron in the layer.

In this project, for the BP algorithm involved randomly exposing the training data to the neural network one at a time and having the weights updated after processing each target. The architecture of the neural network consisted of 7 hidden neurons, 2 output neurons and bias factors. The bias factors can be thought of as including an extra bias weight for each neuron and inputting a constant value of 1.0 into the bias weights.

The input and output layers consisted of neurons with linear activation functions:

$$\varphi(v) = v \qquad (7)$$

The hidden layer consisted of sigmoid activation functions:

$$\varphi(v) = \frac{1}{1+e^{-av}} \qquad (8)$$

Where a in (8) is the slope parameter of the sigmoid activation function.

It should also be noted that the inputs were scaled so that the neural network could process them effectively. Certain parameters were scaled. For example, if one of the input values were 5.332 then that would become 0.5332. Also if for example, parameter three had mostly values like 0.0833 then 0.0833 would become 0.833. However if parameter three also had a few values like 0.1073, then they too would have to be scaled to become 1.07. Basically as many values as possible were scaled so almost all values would be in the same range. (In our case fractional values greater than 0.09 and if possible less than 1.0.)

At each iteration an input data point is chosen at random (to prevent bias toward any data due to its order in the data set). The reason for choosing this particular method was because it was simple to implement and the results for DC and CIR were on average within 6% and 11% error respectively. Also, in a more practical case where the data set would be expected to be large, incremental training would be a good candidate. Batch training, running through all the training data before making a change to the weights would be impractical with very large training sets.

Radial Basis Function Neural Networks

The Gaussian function was used for the RBF neural networks:

$$\Phi_j(x) = \exp\left(-\frac{\| x-\mu_j \|^2}{2\sigma_j^2}\right) \qquad (9)$$

Where μ_j is the jth center and σ_j is the jth radius.

The idea is to choose the centers and radii for the hidden layer that reflects the distribution of the data. Then the weights in the linear layer can be computed. There are many ways of choosing the appropriate centers. The simplest ways are to create a center for every data point in the training set or to choose a fixed number of random training set data points as centers. Another potentially better way to choose the centers is to use the K-means algorithm. In the K-means algorithm, k clusters are selected first, then a re-estimation procedure is used to partition the data into k disjoint sets. The incremental version of this algorithm was chosen and what happens is that k data points are randomly chosen to be initial centers and then the k centers are updated according to the remaining points they are closest to by the equation:

$$\Delta\mu_j = \rho(x - \mu_j) \quad (10)$$

Where ρ is a small constant, x is the closest data point from the training set, and μ_j is the *j*th center.

The weights of the linear layer can be found using the pseudoinverse. In this method, the weights are found according to the equation:

$$W^T = \Phi^+ T \quad (11)$$

Where W is set of weights, T is the set of targets, and the standard pseudoinverse is:

$$\Phi^+ \equiv \left(\Phi^T \Phi\right)^{-1} \Phi^T \quad (12)$$

The radii were set to the constant 4.0 because this gave fairly good results. This is probably because the maximum distance between any two points in our data was found to be roughly 4.36.

Reasons for using RBF networks is because their design allows for efficient clustering algorithms to adapt the hidden units during training without involving the target values. [7] Combine that with a method for calculating the linear layer's weights and training RBFs becomes fast. This is why the training time is much shorter with RBFs than with the BP's training time.

RESULTS AND COMPARISONS

For each test, nine of the 45 data are randomly chosen to be in the test set. All seven fabric properties, fabric weight (W), fabric thickness (T), bending rigidity (B), shear rigidity (G), hysteresis of shear force at 0.5 degrees (2HG), linearity of load-extension curve (LT), and weave were used as inputs to all neural networks except in one case where G was excluded, the reason for which is described later in this section. In the BP method, the best results were obtained with a learning rate of 0.05, momentum of 0, and a slope of 0.1 for the sigmoid functions.

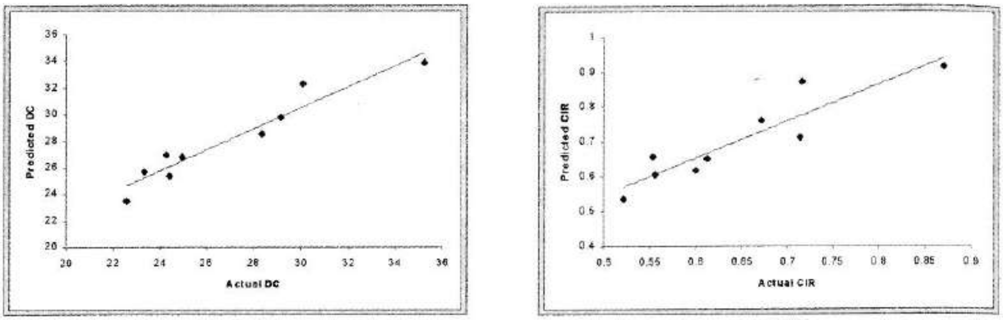
Table I : Mean of average percent errors, and average coefficients of correlation over several tests. Each configuration was run on 10 tests. M is momentum and LR is learning rate.

Method	Parameters	Percent Errors		Coefficients of Correlation	
		DC	CIR	DC	CIR
BP	M = 0	6.18%	10.51%	0.86	0.84
BP	M = 0.01	5.79%	9.93%	0.87	0.74
BP	M = 0.025	5.03%	10.32%	0.82	0.73
BP	LR = 0.1, M = 0	8.55%	14.08%	0.67	0.56
BP (G Excluded)	LR = 0.05, M = 0	5.63%	8.34%	0.85	0.80
RBF	All training data as centers.	8.69%	11.52%	0.71	0.58
RBF	K-means (k=5)	7.85%	12.56%	0.67	0.69
RBF	K-means (k=10)	11.98%	18.23%	0.54	0.40

For the RBF method, both using all training data points as centers as well as the incremental version of the K-means algorithm (with 550 iterations, i.e. using (10) on the data 550 times, and 0.1 for the ρ constant) to find the centers were investigated. A summary of the results for the test sets can be seen in Table I. (Unless otherwise specified, each BP test had a learning rate of 0.05 and was trained on 10000 iterations per test.)

The CIR results were usually worse than the DC results in all cases. While the results of CIR were not as good as the DC results, CIR still had reasonable results in both of the BP test runs with learn rate = 0.05 and momentum = 0. This suggests that CIR is a particularly sensitive parameter and requires very careful and slow convergence.

The BP methods that overall, did the best were the ones with learn rate = 0.05 and momentum values of 0. However when momentum was set to 0.01 (all other parameters being the same), DC results improved slightly. Momentum, as stated earlier can help the network from getting "stuck" in local minima when training. So this may have helped DC but CIR results were not quite as good. The CIR average percent errors improved slightly but its correlation coefficient went from 0.84 (without momentum) to 0.74. Also, the BP method with 0.025 momentum while comparable to the one with no momentum (at least with DC) still had overall worse results. The momentum value may have been to high and so learning was less stable. (High values for parameters such as learning rates can make a neural network learn faster but can also cause it to be unstable.) Good values simply have to be found experimentally because good parameters depend on the specific application and data set. Some of our tests yielded very good results. Fig. 3 shows sample best linear fit graphs using our best case results.



r = 0.96 r = 0.92

Fig. 3. Best Linear Fits for the best case's (a) DC and (b) CIR.

Sometimes excluding an entire variable helps. The decision was made to exclude G and training using the BP method with a learning rate of 0.05 and momentum of 0. G was excluded because it contributed least to the neural network's outputs as can be seen in Fig. 4. (Determined by an analysis of the weights.)

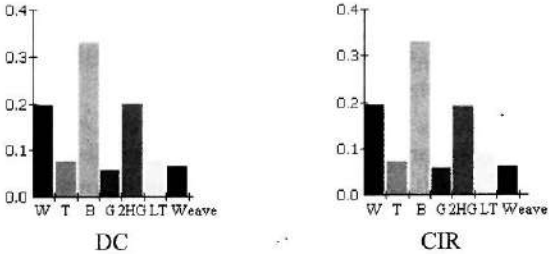


Fig. 4. Contributions of each input variable to the DC and CIR for BP training model.

In comparison to the BP test with the same parameters, excluding G only improved the percent errors slightly. Overall, excluding G gave comparable results but the correlation values were better with G. This suggests that G is still an important factor for our data.

The RBF networks did not perform as well as the ones using BP. Both the average errors and coefficients of correlation were worse than those of the BP tests. This is not surprising because RBF networks typically require 10 times more data to achieve the same accuracy as BP training. Using the targets to train the RBF hidden units would improve the accuracy of the network but that would compromise the speed advantage. [7] Therefore methods such as the K-means algorithm were tested and only resulted in moderate correlation using k=5. It should also be noted that the RBF results were less consistent than the BP results. In the set of tests with k=5, average DC percent errors would range from 5.2% to 14.2%. (For the BP tests with learning rate of 0.05 and momentum of 0, the range for DC was from 4.4% to 7.5%.) Although considering the size of our data set, the RBF performed better than expected.

CONCLUSION

Neural networks provide a means to predict drape coefficient and circularity using the fabric physical and mechanical properties. The two neural network models performed reasonably well but the performance can be further improved. The results of the neural network generalizations were fairly good considering that there were only had 45 data points to work with. The BP method's results were far more promising, which shows the power of BP. The RBF results were not as promising however a further investigation of these methods with more data may give better results for both models. If the RBF network gives acceptable and better results as compared to the multilayer BP, then it may be a better candidate for a practical application because RBF network training is much faster than BP training. The key to the success of using neural networks for drape prediction is the accumulation of a large database of fabric physical and mechanical properties with a wide range of properties.

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Stimuli Responsive Textile Structures

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Conventional textiles are used to cover human body and function as a protective layer for the body from dust, sunlight, wind, and other contaminants present in the normal living environment. It is also used for carrying out technical functions which utilize their flexible and strong structure. However, the textiles may be used for additional function specific to an adverse or extreme climate, job environment or profession to enhance adaptability and/or productivity of the user. When textile assumes an additional function over and above the conventional purpose as mentioned above, it may be regarded as Smart Textile. And if this additional functionality changes with change in use conditions, then textile may be regarded as Active smart or intelligent textile.

At IIT Delhi, we have been working in making smart textile materials which respond to changes in the immediate environment. (i) Thermo-regulated textile, which removes heat when temperature goes up and releases heat when temperature drops, has been developed using phase change materials with transition at near the body temperature (30 °C). These can be effectively used to keep the microclimate near the body buffered from sudden cyclic changes in the environment temperature. Fabrics with heat storage capacity of about 80-100 J/g have been produced and are being further developed for use in uniforms of pilots of fighter aircrafts. (ii) Shape changing fibres, yarns and fabrics have also been developed using a novel class of stimuli sensitive copolymers which can be readily processed and chemically integrated to textile substrate. These allow development of new composite yarns and fabrics that change shape reversibly by capturing moisture from the surroundings depending on the environment temperature and pH. These structures change shape to a very large extent and with fast response time.

Such materials may be used for making environmentally responsive textile, artificial muscles, and other biomedical applications.

TEMPERATURE-RESPONSIVE TEXTILES

The stimuli-sensitive polymers are smart materials being researched all over the world. They find applications in the medical field and have potential applications in separation, artificial muscles, molecular separation and enzyme-activity control [1,2].

The temperature sensitive polymers (TSPs) show transition at their Lower Critical Solution Temperature (LCST) called the transition temperature. These polymers have both hydrophilic and hydrophobic groups in their structure. Below LCST, the hydrophilic interactions dominate and polymer becomes soluble in water, while above this temperature hydrophobic interactions dominate and polymer becomes insoluble in water [3]. These polymers find applications when polymerized in gel form. The gels change shape by swelling in water below transition temperature and deswell above transition temperature.

The major drawbacks of the current stimuli-sensitive polymer-gel structures are their weak mechanical properties and poor transitional response. Processing of these materials into thin shapes and their integration to textile materials is likely to solve the current problems and also develop responsive textile materials for smart textile.

As suggested above, at the Indian Institute of Technology, Delhi (IIT, Delhi), we have attempted to solve these limitations by processing a suitably designed TSP into various forms such as structurally strong thin films, fibers, coatings, and chemically integrated TSP with yarns and fabrics.

The successful processing of TSP as mentioned above involved various critical investigative steps as enumerated below:

- Synthesis of a suitable TSP system which had transitional response tunable in a wide range of temperature.
- Production of TSP in high molecular weight, suitable for its conversion into high strength thin structures.
- Development of a method for stabilizing processed forms, for example, possibility of carrying out chemical bonds among polymer chains, and with textile substrates after processing that would not compromise responsive behavior of the resultant fibers.

EXPERIMENTAL SECTION

A series of TSP copolymer "poly(*N-tert*-butylacrylamide-*ran*-acrylamide) (PNTBA)" was synthesized in both gel (using *N,N'*-methylenebisacrylamide during the process of polymerization) and linear form using free radical polymerization with controlled dosing of comonomers [4,5]. The solution of linear copolymer (27:73) containing polycarboxylic acid crosslinker and catalyst was processed into thin films (10 to 200 m), fibers (30 to 50 m), and coatings on to cellulosic yarns and fabrics [Save (2003), Agrawal (2004), Save (2004), Save (2004)]. The processed forms were dried and cured at 150 to 200 °C for 5 to 25 minutes. The responsiveness of the processed structures immersed in water bath was determined by measuring the swelling percentage and swelling kinetics with change in the temperature of the water bath [4-8].

The TSP synthesized in conventional gel forms could be cut with difficulty into 2mm thick disks. On the other hand TSP could be readily converted into finer forms and subsequently stabilized through crosslinking. The crosslinks (i.e., covalent bonding) were formed using polycarboxylic acid between amide side-groups of the copolymer and hydroxyl-group of the cellulosic substrate (in case of coatings).

RESULTS AND DISCUSSION

The processed forms were found to change shape as the temperature of the water bath was altered across their transition temperature of 21°C (Figure 1). The structures could be repeatedly swollen and deswollen by decreasing and increasing the temperature of the water bath, respectively.

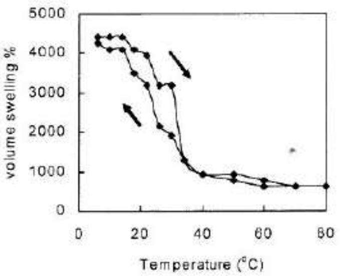

Figure 1. Change in the shape of film with change in temperature of the water bath.

The transition properties and the response time of the processed forms in comparison to the polymer-gel disks are given in Table 1.

Table 1. Transitional properties of various forms of TSP.

Sample type	Thickness	Swelling (change in shape) %	Time for 70% of equilibrium swelling	Time for complete deswelling from equilibrium swelling
Gel disk (conventional)	2 mm	490	90 min	50 min
Film on glass	200 μm	1860	5 min	5 min
Film on glass	10 μm	2980	~1 min	10 sec
Coated on Fabric	23% add-on	800	5 min	1 min
Coated on Yarn	39 μm	4500	3 min	10 sec
Fiber	30 μm	17800	<5 sec	<1 sec

The TSP prepared in conventional gel form as a 2 mm thick gel disks, showed a swelling of 490 %, and took 90 minutes to attain 70 % swelling, while the deswelling took 50 minutes.

Structurally strong thin films

The films of TSP (10 to 200 m) showed a significantly enhanced magnitude of response depicted by an increase of 4 to 6 times in the swelling ratio compared to the 2 mm thick gel-disks. The response time reduced drastically to 1 minute for swelling and a few seconds for deswelling (Table 1).

Responsive Breathable Fabric

A breathable fabric was prepared by integrating the TSP onto a cotton fabric with 23% add-on. The coating on the fabric showed a swelling ratio of around 800% and a response time of 20 minutes to equilibrium swelling. The water-vapor transmission rate (WVTR) values of the TSP integrated breathable fabric were measured as a percentage of control uncoated substrate. The transmission percentage at 20% relative humidity for TSP-fabrics (Figure 2) were found to change across the transition temperature (15 to 45 °C) from 58% to 94% compared to a comparative non-responsive breathable fabric (made using poly(acrylamide) coated fabric), which changed only from 70% to 94%. The difference in percentage transmission, due to change in the environment temperature, shows the responsive (smart) behavior of the TSP-fabrics. Similar results were obtained for other relative humidity conditions.

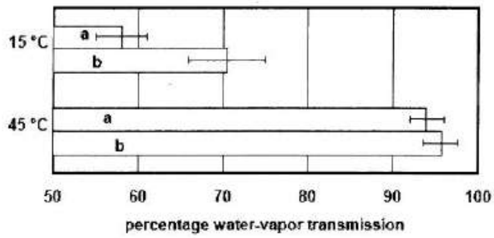

Figure 2. Water-vapor transmission for coated fabrics shown as a percentage of control (uncoated cotton fabric) at 20 % relative humidity. (a) Responsive breathable sample made from TSP coated cotton fabric and (b) Non-responsive breathable sample made from polyacrylamide coated cotton fabric.

Shape Changing Fabric

Another responsive model fabric was fabricated using TSP coated yarns. The percentage cover of the model fabric (immersed in a water bath) changed from 0% at 6 °C, to 39% at 30 °C, and 57% at 80 °C. The change was completely reversible for several cycles. The change in the porosity (percentage cover) with temperature can be clearly seen in optical microphotographs given in Figure 3. This response of the percentage cover is quantitatively shown in Figure 4.

Shape Changing Fibers

The TSP was also successfully converted into a shape changing textile fiber of fine diameter. The fiber underwent change both diameter and length with change in temperature. The time for 70% transition (swelling) was found to reduce dramatically from 90 minutes for the 2 mm gel disc to less than 5 seconds for the TSP fiber, while the change in shape (swelling ratio) of the fibers increased by 36 times (Table 1). Figure 5 shows an optical micrograph of the diametric change of the fiber immersed in water. The rate of transition of the fiber is shown in the Figure 6 (i) and the transition temperature is shown in the Figure 6 (ii).

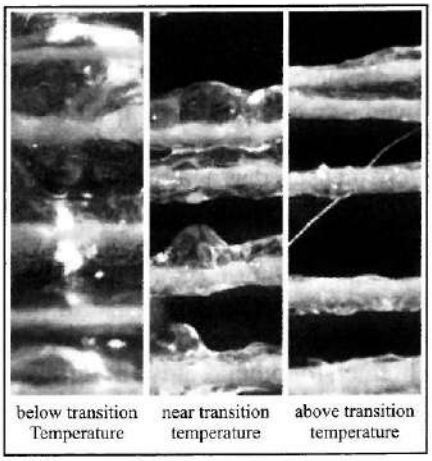

Figure 3. Optical micrographs at 10× of model fabric at different temperatures.

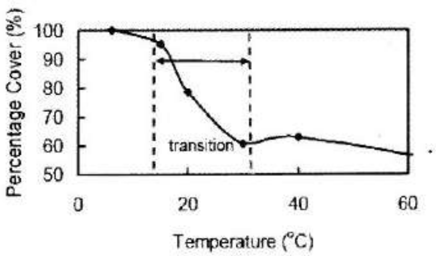

Figure 4. Change of percentage cover of the model fabric with temperature.

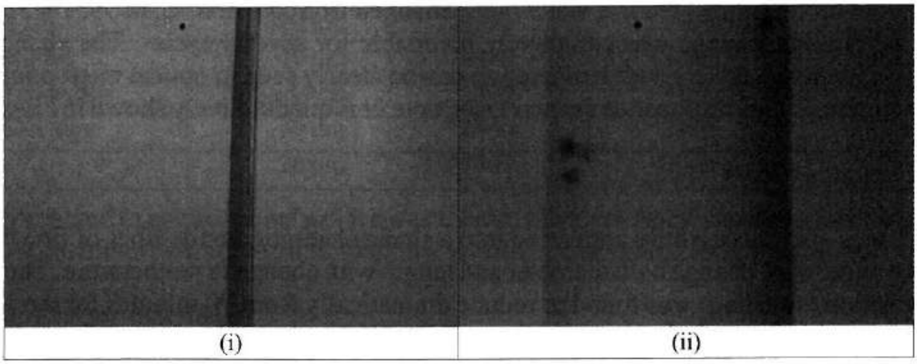

Figure 5. The optical micrograph of shape changing fiber at 100.
(i) fiber in water at 80 °C; (ii) fiber in water at 6°C.

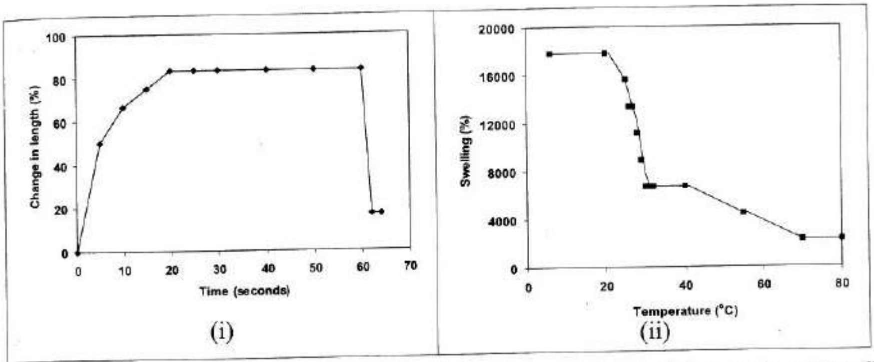

Figure 6. (i) Rate of transition and (ii) transition temperature of shape changing fibers.

pH-RESPONSIVE TEXTILES

Introduction & Experimental

Similar to the TSPs, pH-sensitive polymer (PSP) structures reported in the literature [9] also suffer with the slow response time, poor magnitude of response, and weak mechanical properties. Since these materials are prime candidates for making artificial-muscles, sensors and actuators; thin fiber shapes with enhanced transitional properties are desirable. In one of the recently reported approach [10], oxidized polyacrylonitrile (PAN) fibers are hydrolyzed to give composite structures containing both acrylic acid and oxidized cyclic PAN moieties. Acrylic acid moieties provide the pH response while oxidized PAN regions provide the strength and structural integrity. However, the response of such structures has not been optimized with regards to conditions of oxidation and hydrolysis. At IIT Delhi, we have attempted to optimize these parameters to produce pH-responsive fibers with enhanced response. However, these fibers still suffer with major drawbacks of being black (due to oxidation) in colour, brittle, and high cost of production. The details of production and properties of these fibers are given in a separate paper in this proceeding [11].

In order to overcome the above drawbacks, another attempt using a novel approach was made to solution spin pH sensitive fibers from a specially designed copolymer of acrylic acid and acrylonitrile. Unlike oxidized PAN fibers, these fibers are white in color, have high impact strength and show even higher response. The interesting feature of the newly designed fibers is that it is not chemically crosslinked. Rather the physical structure of the fiber has been tuned to give both responsiveness and structural stability.

RESULTS AND DISCUSSION

The pH sensitive fibers exhibited increase in size at pH 10 in the range of ~1300% and decrease in size at pH 2 to near the original volume (range of 120-180 %) during the first two cycles;

however in the subsequent cycles the increase is about 3300 % while nearly same shape and size was obtained at lower pH. The increase in the swelling ratio from the third cycle onwards could be due to opening-up of the structure. The response was reversible and stable in subsequent cycles.

THERMO-REGULATED TEXTILE

Introduction

Thermoregulated textile is another very important area of research to make environmentally responsive textile [2]. There are numerous situations where these can be beneficial and find applications. These include professions where the person has to undergo extreme changes in immediate climate. For example pilot's uniform in a fighter plane, soldier's uniform in extreme climate zones, uniforms for workers working at extreme temperatures, fire fighters, tents and temporary structures in extreme climates, automobiles, etc. One of the main applications where IIT Delhi jointly with DEBEL, Bangalore is placing a particular emphasis is the development of thermoregulated clothing for pilots of fighter planes. The pilot has to go through extreme change in temperature during a flight. Their imperious anti-gravity suits and the high temperature of the cockpit during the initial flight period put enormous thermal induced stress on their alertness and analytical capability. Clothing with the encapsulated phase change materials (PCM) can help to retain a constant temperature buffer and provide better comfort.

PCMs are the materials which undergo a phase change from solid to liquid by absorbing certain amount of heat and a phase change from liquid to solid by releasing certain amount of heat. Because these materials have to exist as liquids in one of the transition states, they need to be encapsulated to protect them from leaking out of the clothing during a phase change.

EXPERIMENTAL SECTION

At IIT Delhi, dozens of PCM were scanned for their potential application at low temperature, at near the body temperature and at high temperature. Out of several selected for near the body temperature application, octadecane was found to be the most suitable for the above mentioned application. It has a high enthalpy value of 240 J g^{-1} and its melting temperature is near to the human body temperature that is around 28 °C.

Octadecane was encapsulated using two different methods. The in-situ polymerization and interfacial polymerization method. These two were found suitable among the various techniques known for encapsulations. In the first process, a prepolymer of melamine-formaldehyde was prepared to which emulsifier and water was added. Thereafter, the octadecane was added slowly, while the mixture was stirred at a high rpm. In situ polymerization was carried out in the prepared emulsion by slowly raising the temperature from 40 °C to 68 °C for a predetermined time. In the second method, PCM was encapsulated by interfacial polymerization technique. The oil phase was prepared by mixing n-octadecane (pcm), the core monomer toluene-2, 4-diisocyanate (TDI), the cyclohexane. The oil phase emulsified in an aqueous phase. The bulk monomer diethylene triamine (DETA) was added to the emulsion. The encapsulation was carried out at 60 C for 1.5 hr. The focal point of the study was to increase the core content, stability, and efficiency of encapsulation.

RESULTS AND DISCUSSION

In the first process capsules were achieved with a core content of 62.2% (Figure 7). However, still the studies are being carried out in order to optimize process parameters such as core to wall ratio, melamine and formaldehyde molar ratio, emulsion and encapsulation temperature, and time to maximize core content, good yield, stability and reproducibility of capsules.

In the second process, the microencapsulation was carried out at different monomer to core ratio, octadecane to cyclohexane ratio, and other such parameters. The microcapsules produced at the octadecane to cyclohexane ratio of 6:1 and monomer to core ratio of 1:1 showed the highest core content of 70% and highest encapsulation efficiency of 97%. The microcapsules produced at the monomer to core ratio of 0.5:1 and the octadecane to cyclohexane ratio of 1:1 showed the lowest core content of 39%, lowest encapsulation efficiency of 55%. With increasing monomer to core ratio, the core content decreases and the encapsulation efficiency increases. While, as the octadecane to cyclohexane ratio increases, both the core content and the encapsulation efficiency increases.

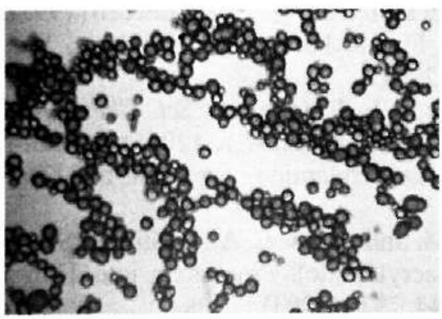

Figure 7. Optical micrograph of the PCM capsules at the magnification of 500×

CONCLUSIONS

The research at IIT Delhi has made several successful attempts in developing truly smart textile materials in the last few years. These materials respond actively to the changes in the environment. For the first time, shape changing fibers, yarns and fabrics have been produced with the help of suitably designed stimuli sensitive copolymers. Textiles that respond quickly and reversibly to small changes in temperature and pH have been successfully demonstrated. The processed fine structures were able to overcome the major drawbacks, such as, slow response, poor efficiency, and poor mechanical properties exhibited by stimuli-sensitive hydrogels reported in the literature. Similarly, encapsulated PCM have been developed with very high core content and high encapsulation efficiency. These are stable to high temperature and multiple cycling. Using these, thermo-regulated textile for various applications may be developed in the near future.

The above materials would enable development of intelligent structures for producing environment adaptable textile, artificial organs/muscles, biomedical devices, and robotic applications. Thermoregulated-textiles using microencapsulated PCMs shall enable humans to achieve new dimensions of success in their respective fields of professions even with extreme-environment. These studies open up a whole new area of application in truly smart or intelligent textiles.

ACKNOWLEDGEMENTS

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A New Route To Stimuli Responsive Fibres : Copolymerization Of Acrylonitrile & Acrylic Acid

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Stimuli sensitive polymers are gaining much interest due to their potential application in smart fabrics, biomedical, robotics, and chemical industry. For all these applications these polymers are used in the crosslinked form. Contrary to hydrogel, polymeric fibers exhibit very good mechanical properties as a result of high degree of oriention and crystallinity. Copolymers of acrylonitrile and acrylic acid are expected to result in fibers with lateral organization of crystallites in oriented structure as well as pH sensitivity. In the present study we have synthesized stimuli sensitive polymers by copolymerizing crystalline segments of acrylonitrile and responsive segments of acrylic acid. Controlled free radical polymerization was carried out in toluene using á, á'- azobisisobutyronitrile (AIBN) as initiator. A series of copolymers were synthesized by varying the percentage of acrylic acid in the monomer feed from 10 to 50 (mole %). The resulting copolymers were isolated, dried, characterized and solution spun to obtain fibers. The transition properties of these fibers i.e. equilibrium swelling %, rate of transition, cyclability and hystersis were studied. The fibers exhibited volumetric swelling in the range of 1300% and deswelling to near the original volume (range of 120-180%) during the first two cycles; however in the subsequent cycles the volumetric swelling increased to about 3300% while nearly the same shape and size was obtained on deswelling.

The polymeric networks that can sense the pH of their environment as a signal, judge the magnitude of the signal and change their properties accordingly are known as pH responsive hydrogels. The pH sensitivity of the gels is influenced by nature of ionizable groups, cross linking density and polymer composition. Smart pH sensitive polymers have been investigated for applications in drug delivery systems, actuators, artificial muscles and membranes, where quick responsive gels are desired. Depending upon the end application, different polymers/copolymers systems based on poly (hydroxyalkyl methacrylate), poly (acrylamide), poly (N-Vinyl pyrrolidone), poly (acrylic acid), and poly (vinyl alcohol) in the hydrogel form have been reported [1-5]. However, since the process is diffusion controlled, the gel swelling and shrinking is strongly dependent on the thickness and surface area of the gel. Therefore, a reduction of gel size has been thought to be the only way to achieve quick response. Our group has recently reported the conversion of temperature sensitive copolymers into thin films and fibres [6, 7]. Contrary to hydrogels, polymeric fibres were found to exhibit better mechanical strength and enhanced transition properties. The preparation of pH responsive fibres based on polyvinyl alcohol [8] and modified acrylic fibres has also been reported [9]. The modification has been attempted on oxidized polyacrylonitrile fibres to provide stable structure and responsive acrylic groups. However, the response of such structures has not been optimized with respect to conditions of oxidation and hydrolysis. At IIT Delhi, we have attempted to optimize these parameters to produce pH-responsive fibres with enhanced response [10]. However, these fibres still suffer with major drawbacks of being black in colour, brittle, and high cost of production.

The current study is an attempt to overcome the above drawbacks, by using a novel approach to solution spin pH responsive fibres from a specially designed copolymer of acrylic acid and acrylonitrile. Here the acrylonitrile entities are expected to impart strength to the fiber while the acrylic acid units render pH responsive behaviour.

EXPERIMENTAL

Materials

The monomers acrylic acid (AA) and acrylonitrile (AN), toluene, the initiator á,á'-azobisisobutyronitrile (AIBN) and the solvents diethyl ether and dimethylformamide (DMF) with the minimum assay or exceeding 99% and more were used without further purification.

Copolymer synthesis

Free radical copolymerization was carried out in a four neck reactor in toluene at 651C under nitrogen atmosphere. The monomer concentration was fixed at 20 %. The content of acrylic acid in the feed was varied from 10.5 to 50 (mole %). Initiator AIBN (0.15 wt % on the weight of monomer) was used to initiate the polymerization [11]. Acrylonitrile was taken in a reaction flask, containing required quantity of toluene and degassed for 30 minutes. After that the initiator solution was introduced into the reaction flask to start the polymerization. To control the composition of copolymer, the comonomer AA was introduced in small regulated doses. The reaction was continued for 8 h. After the polymerization, the reaction mixture was cooled and the copolymer was precipitated in diethyl ether solution. The final product obtained was in the form of white precipitate. The copolymer was washed twice with diethyl ether to remove any traces of toluene. The purified copolymers were dried in a vacuum oven at 60C. Gravimetric yields of these copolymers were found to 65%.

Copolymer characterization

The intrinsic viscosity of the copolymers was determined in DMF using Ubbelohde viscometer in a constant temperature bath at 30±0.1°C. The FTIR spectra were recorded on a Perkin-Elmer 883 spectrophotometer to ascertain the incorporation of the acrylic acid units in the copolymer and to determine the composition of copolymer. The ^{1}H- NMR spectra of the copolymers were also recorded under the standard conditions at 25 °C in DMSO-d6 on a Bruker 300-MHz spectrophotometer.

The DSC thermograms of the copolymers were recorded on a Perkin-Elmer DSC-7 in a temperature range of -10°C to 250°C at a heating rate of 5° C/min.

Solution spinning of pH Sensitive fibres

The dope solution was prepared by stirring the purified and dried copolymer powder in DMF. The solutions were kept in vacuum at room temperature to allow deaeration before spinning. Fibres were extruded using a syringe type monofilament extruder into a coagulation bath containing various proportions of DMF: water. The fibres after complete coagulation were dried under taut condition in air, and subsequently annealed at different temperatures ranging from 80-150°C for 2 h to impart strength to the fibres.

Swelling behaviour

The swelling behaviour of fibres was studied by immersing them in varying pH solutions. The fibres were left at each pH for 45 minutes. The diameters of the fibres were measured in a Lieca microscope before and after subjecting them to alkaline and acidic solutions. The lengths of the fibres were also measured before and after each transition. The volumetric swelling was obtained from change in diameter and length of fibres.

i) The equilibrium swelling of the fibres in terms of diameter and length were measured in alkaline solutions (pH 10). The measurements were continued until equilibrium swelling was attained. The swelling was measured for up to 180 min.
ii) The kinetics of swelling of the fibers was studied by immersing the sample in pH 10 solution and monitoring the change in length of the fiber with respect to time.
iii) The reversibility of the pH-induced transition was studied for the responsive fibres by placing them in alkaline and acidic solutions alternatively for four cycles.
iv) The Hysteresis during transition was studied initially by subjecting the fibre samples to increasing pH solutions and subsequently the deswelling was recorded by subjecting to acidic pH solutions thereby reversing the cycle.

RESULTS AND DISCUSSION

As discussed earlier in the current approach the acrylonitrile monomer has been chosen to impart fibre-forming properties while the acrylic acid has been selected as a responsive monomer. The relative proportion of two monomers in the fibre and the microstructure of the copolymer determine the ultimate properties of the fibre. Therefore, the success of the process depends on the following two challenging steps.

1. Engineering and synthesis of linear responsive copolymers of acrylic acid and acrylonitrile
2. Spinning of responsive copolymers into stable, uniform responsive fibres.

Synthesis of pH sensitive copolymers

The synthesis of linear pH sensitive copolymers involved selection of suitable synthesis conditions i.e. initiator, solvent, temperature and composition. Since the reactivity ratios of the two comonomers are very different, the incorporation of two monomers in the desired proportion also required controlled feeding of more reactive comonomer (i.e. acrylic acid). The regulated dosing of acrylic acid was also necessary to avoid/prevent the formation of acrylic acid homopolymer. High molecular weight copolymers with intrinsic viscosity (2.0 dl/g) were obtained .As shown in table 1 the acrylic acid content in the monomer feed during copolymerization was varied between 10-43 mole %. The acrylic acid content in the feed was limited to a maximum of ~ 50 mole % due to the necessity of producing water insoluble copolymer.

Table 1 Sample codes for copolymers synthesized with varying feed ratios of acrylic acid with acrylonitrile.

Sample code	Acrylic acid comonomer in the monomer feed (mole %)
AA10	10.5
AA16	15.9
AA29	28.6
AA33	33.4
AA38	37.9
AA43	42.71

The change in the copolymer composition was determined using FTIR and NMR. In the FTIR spectra of these copolymers, a progressive decrease in the CN peak height with simultaneous increase CO peak height was observed, as the percentage of acrylic acid in the copolymer increased. The proposed structure of the copolymer is as shown in the Figure.1

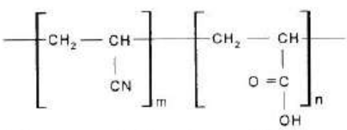

Figure 1.Proposed structure of the copolymer.

Solution spinning of the stimuli sensitive fibers and heat treatment

Like polyacrylonitrile, the synthesized copolymers were soluble in DMF, therefore solution wet spinning was carried out using DMF as a solvent and DMF: water mixture as an effective coagulant. The coagulation bath composition was varied to optimize the coagulation of the fibre. The spun fibre was washed thoroughly with water and drawn under hot conditions to attain enhanced orientation of the fiber. Mechanically strong fibres were obtained for all above compositions (AA10-AA43). To understand the effect of the structure of the fibre on swelling response, the annealing of these drawn fibres was carried out in taut condition at different temperatures (in the range of 80-150 C) for a period of 2 hrs. The annealing of the fibres resulted in improved mechanical properties and stable structure during subsequent swelling studies (treatment to alkaline and acidic pH).

Evaluation of transition properties

The response of fibres to variation in solution pH was determined by immersing the fibres at different pH solutions for 45 min. Among all the fibre samples, fibre obtained from copolymer AA43 exhibited the highest response. Therefore, in the current study all the transition properties were evaluated for this fibre sample (solution spun using copolymer AA 43). The variation in diameter of the fibre with change in external pH solution is shown in figure 2. The fibre showed swelling and deswelling in alkaline and acidic pH solutions respectively. The pKa of polyacrylic acid is 4.3, therefore below pH 4.3 the H^+ ion concentration is very high. This effectively suppresses the ionization of carboxylic groups and the carboxylate groups change to -COOH groups. The polymeric chains in the fibre remain in the coiled state resulting in deswelling. As the pH is increased above the pKa, the concentration of free ions in the gel fibre also increase causing an increase in the negatively charged carboxylic groups showing high swelling because of repulsive forces between the similar charges of carboxylate ions. When the carboxylate groups in the polymer chain are fully ionized the effect of electrostatic repulsion is higher and the gel fibres expand significantly at about a pH of 10. So the Equilibrium swelling studies of the fibers were conducted by immersing the fibres in pH 10 solutions. The equilibrium-swelling curve for the fibre sample AA 43 is shown in Figure 3. For this experiment the fibre was placed on a glass slide in slack condition and the glass slide along with fibre was immersed in pH 10 solution for determining the change in dimensions. The fiber attained equilibrium swelling in 120 min with a volumetric swelling of about 2160 %. However, nearly 65 % of the change was complete in 90 minutes. A hysteresis was observed in that the swelling did not start until the pH was increased above 6 and similarly in the reverse cycle the deswelling did not begin until the pH was decreased below 5.5.

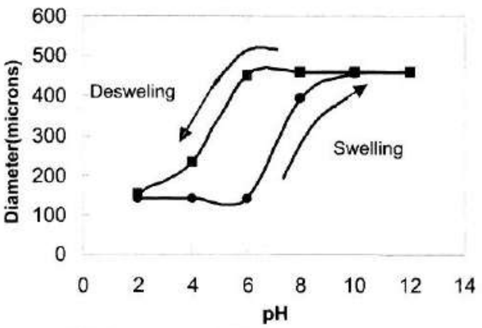

Figure 2. Diameter of fiber sample AA 43 as a function of pH of the external solution while swelling and deswelling.

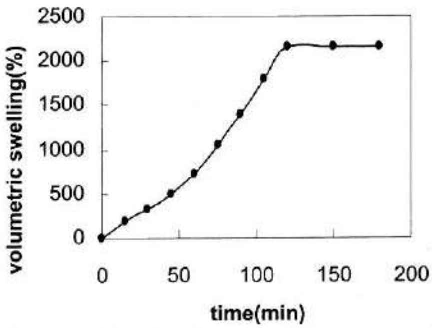

Figure 3.Equilibrium swelling curve of the fiber sample AA 43

The rate of transition in terms of change in length of fibre with time was also investigated. The rate of transition was found to depend on the strength of alkali solution. As shown in figure 4, when immersed in pH 10 solution, the rate of swelling was slow up to about 30 minutes (0.143 %/min), but after 30 min the rate of swelling increased substantially and reached a value of 0.45 %/min. The fibres exhibited reversible swelling /deswelling behaviour depending upon the pH of the solution. Reversibility studies were carried out by immersing the fibre in the desired pH solution in vertical form (in a measuring cylinder). A small weight was attached to the lower end of the fibre to avoid curling of the fibre for precise length measurement. The Reversibility of transition was evaluated for four swelling deswelling cycles. The as-spun fibre AA43 showed higher volumetric swelling in comparison to the drawn and annealed fibres. However, the as-spun fibres were not able to withstand repeated cycling .The samples annealed at 80 and 100 C showed superior mechanical properties compared to as spun untreated fibre but were unable to withstand more than six cycles. The fibres treated at 120

C were found to be very stable to repeated cycling and no noticeable deterioration in strength was observed even after ~15 cycles. A marked decrease in response of the fibres was observed on increasing the annealing temperature to 150 C. In order to obtain a compromise between high response and stable structure the annealing was carried out at 120 C. The fibre sample AA43 annealed at 120 ° C exhibited excellent reversibility as shown in Figure 5. During the first two cycles the swelling was in the range of ~1200 to 1300 %. Subsequently the swelling % increased to ~ 3300-3600 %. This may be due to the fact that the fibers underwent conditioning in the first two cycles and then in the subsequent cycles showed stable response. The higher extent of volumetric swelling during reversibility study (3300 %) compared to equilibrium swelling of 2160% of may be attributed to the difference in the test method employed.

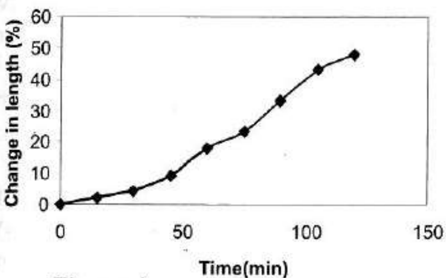

Figure 4

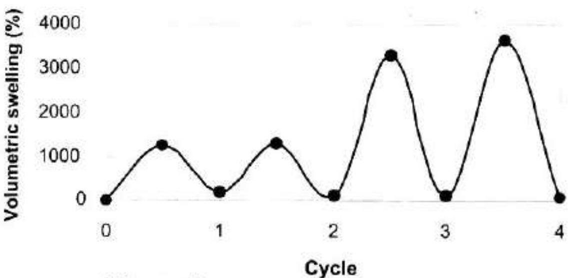

Figure 5

CONCLUSION

Poly (Acrylonitrile-*b*-Acrylic acid) copolymers with varying feed ratios of AN and AA (10-43 % AA) were synthesized and converted to fibres by solution spinning. These fibers were tested for their transition properties. The percentage of acrylic acid in the copolymer was found to have a marked effect on the pH sensitive behaviour of the fibers. The fibre sample prepared with a copolymer containing 42.71 mole % of acrylic acid (in the feed) was found to show good response to the pH of external solution. The stabilization (annealing) conditions were also found to influence the mechanical properties and response of the stimuli sensitive fibre. Stable, reversible transition with a volumetric swelling in the range of 3300-3600 % was obtained for the fibre AA 43 annealed at 120 °C These fibers due to their higher strength and enhanced response compared to gel rods are an attractive alternatives for various potential applications.

Acknowledgement

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Investigating Shape Memory Technologies for Smart Fabric

TAO YU WAN, GK STYLIOS & FAN HAN

Intelligent textiles with self-regulating structures and performance in response to environmental variation constitute a new application field in the scientific frontier of smart materials. By incorporation shape memory alloys SMA or shape memory polymer SMP with appreciable fabric designs, textile can be engineered to enhance the performance and particularly the aesthetic appeal of new textiles. In this paper, we have investigated a series of related technologies associated with the realization. Main technologies includes the training procedure of Shape Memory Effect (SME) in SMA and SMP, the regulation of phase transformation temperatures in SMA, the manufacture of SMP yarns for the requirements of fabric design. Further attention is also paid to the combination of SMP or SMA with textile design of different fabric yarn for promoting SME.

Intelligent textiles based on shape memory effects constitute a new field in the scientific frontier of smart materials. The attractiveness of these smart fabrics is their unique capabilities to rapid and reversible change of structure and properties in response to relatively small environmental variation. Most current research is directed toward synthesis of communication, robotic muscles, sensors, and quality control with various types of responsiveness in which SMA and SMP can be stretched and deformed but return to their original shape at a given pre-programmed temperature. Jin Sung Company has used a superealistic material to develop memory breast bra that uses SMA to retain the shape of the breast after warming from the human body. The same principle is also being used by an Italian company to produce shirts that 'iron' themselves at body temperature. Another Italian fashion house has designed a shirt which rolls up its sleeves when the body gets warm [1, 2].

Recent advances in SMA and SMP have inspired us to create intelligent textiles with self-regulating structures and performance from a blend of traditional textile materials and shape memory materials. The main limitation for developing the smart textiles comes from the high SME training temperature of SMA which conflicts with the much lower melting point of textile fabric material, and low recovery force in SMP materials. Consequently, the project focuses on the systematically study of the practical SME training process of SMA and SMP appropriated for controlling the aesthetic appeal performance of flexible fabrics, combination of regulating phase change temperature. Further attention is also paid to the design in combination of SMP or SMA with different yarn materials for promoting SME.

Shape Memory Technologies for Smart Fabrics

Smart Fabrics Based on NiTi SMA

The first investigation is devoted to thermomechnical treatment for the regulation of phase transformation performance of NiTi SMA used in textile fabrics. Investigations have been carried out on a commercial Ti-49.8 at.% Ni wire of 0.2 mm and 0.3 mm diameter with transformation temperatures (A_s = 25.5, A_f = 46.5, M_s = 10 and M_f = -14.5°C measured by DSC). NiTi primary wire of cold work state was annealed at a temperature about 400 to 650 °C for 0.5 to 2 hours in order to regulate phase transformation temperatures of the SMA alloys. It is demonstrated that a solution treatment at 650 °C/60 min and ageing treatment at 380 °C/100 minutes yields an A_f of about 40 °C, while ageing treatment at 480 °C/100 minutes yields an A_f of about 48 °C. The variation is consistent with the formation of lenticular Ti_3Ni_4 precipitates. When the specimen is annealed lower than 400 °C, the Ti_3Ni_4 precipitate particle is fine and the dispersion density is high, so the precipitate Ti_3Ni_4 has great coherence with the matrix. However, when annealed higher than 400 °C, the precipitate Ti_3Ni_4 grow up and the low dispersion density destroys the coherence between Ti_3Ni_4 and the matrix [3, 4].

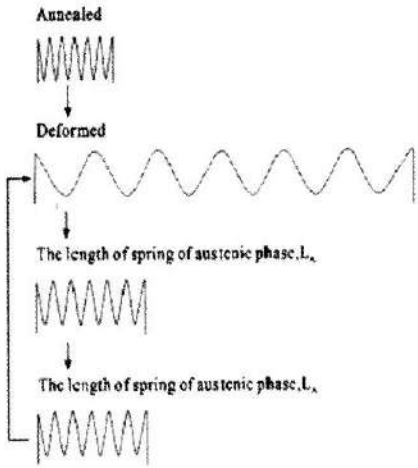

Figure 1. Training Scheme of the Two-way SME Springs

A thermomechanical training process for the two-way SME in SMA springs is schematically shown in Figure 1.The effect of annealing temperature on SME is also related to the change of internal stress fields and the distribution of dislocation, as well as the states of parent phase due to shape and disperse degree of precipitates Ti_3Ni_4 [5-10]. An anisotropic dislocation structure is formed in the austensitic matrix after SME training procedures. This dislocation structure creates an anisotropic stress field in the matrix, which guides the formation of martensite into variants of preferential orientations in relation to the deformation adopted in the training procedure, thus resulting in a macroscopic shape change during subsequent thermal transformation cycles. At lower annealing temperature, the dislocation density and strength of materials of the austensite state were very high, which prohibited the reorientation of matensite, so a two-way shape memory effect was weak. When the annealing temperature increased, the dislocation density and the strength of austensite decreased. After deformation, the reorientation of matensite occurred, which led to the change of internal stress fields. Therefore, with the annealing temperature increasing, the shape memory recovery rate also increased.

Figure 2 illustrates the shape memory recovery process of a SMA spring. Figure 3 illustrates shape memory recovery of smart textile having the trained SMA spring varied with temperature, in which the shape of the smart fabric will vary as the variation of the trained SMA spring in wearied in fabric. In this case smart fabrics can display two-way shape memory effect when the spring is trained for two-way SME.

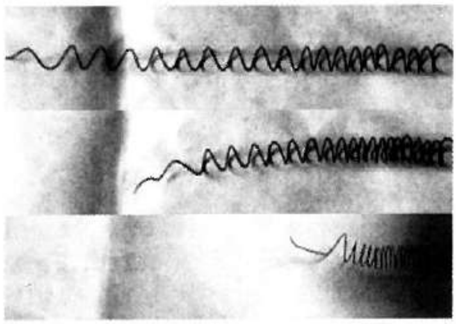

Figure 2. Shape Memory Recovery of SMA Spring

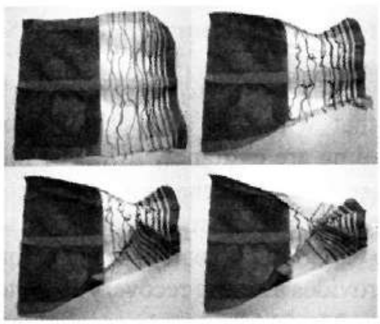

Figure 3. Shape Memory Recovery of Smart Textile Having SMA Spring Varied with Temperature

Figure 4 illustrates some complex examples of the trained shape memory texture structure of SMA, by the clamping devices shown in Figure 5. After 650 °C/2h solution treatment, an aged treatment of 450 °C for 90 minute is introduced to improve the flexibility of the NiTi wire for weaving into fabric by the increase of A_s and A_f of the SMA. For SME training of the SMA fabric, initially SMA woven samples, covered with clap devices, are heated at an oven at 450 °C for 0.5 hour when kept with the binder, and then quenched in water. The shape of the SMA woven fabric was able to be transformed from an initial predestined state at a low temperature, into a trained coil state at a high temperature, with a high rate of shape recovery rate, which verify the effectiveness of the techniques for training textiles based on SMA.

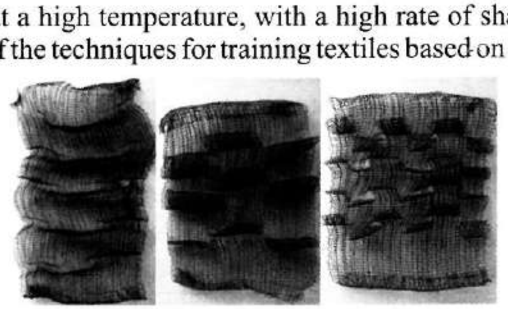

Figure 4. Examples of Shape Memory Fabrics after Shape Memory Training

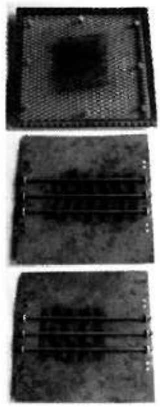

Figure 5. Clamps for Shape Memory Training of SMA Textile Fabrics

However, the amount of recoverable strain in two-way memory behaviour is generally about 2% which is much lower than that which is achievable in one-way memory (6-8%). The transformation forces upon cooling are extremely low. The memory can be erased with slight overheating at above 250 °C. In order to solve the limit in the actuation in the smart textiles, a bias force from another elastic material or structure may be designed to the textiles including a one-way SMA. The idea is based on the variation of a pair of balance forces with temperature. When the temperature is over A_f, SMA provides a strong recovery force to exhibit a shape memory effect. When the temperature is below M_s, SMA provides a weak recovery force and the ability of recovery comes from the elastic behaviour of remaining materials in fabric composite.

Smart Fabrics Based on Shape Memory Polymers

The mechanism of shape recovery of SMP is dependant on the combination of a partially crystalline hard segment and a soft amorphous segment at the transition temperature T_g. Above T_g, the permanent shape can be deformed by the application of an external stress. After cooling below T_g, the amorphous segment is 'frozen' in a glassy non-crystalline state of high elastic modulus dramatically [11], and hence obtaining the temporary shape. The sample recovers to its permanent shape upon heating to $T > T_g$. Investigations have been carried out on polyurethane SMP in which T_g is 25 °C. The raw resin pellet is dried for 8 hours in a hopper circulation oven at 80 °C until moisture is less than 0.03%. Without drying the resin, its viscosity becomes too low when melted, causing deformation by foaming, flashing and dropping at the nozzle. The temperature profile of machine and materials suitable for processing of SMP yarn of 0.4 mm to 0.8 mm diameter using a die diameter of 1mm, are as fellows:

Rear: (Feed Zone):	170-180°C
Center: (Compression):	175-185°C
Front: (Metering Zone):	170-180°C

The key of this operation is to control the viscosity of SMP in the nozzle at the extrusion machine, while assuring the uniform melting of polymer. The viscosity of SMP is more thermal-dependent than traditional polymers, requiring stricter temperature and processing controls for extrusion. In order to control the diameter size of the SMP yarn, the extrusion rate of yarn has also to be regulated.

The shape training and recovery process for SME in SMP samples is schematically shown in Figure 6. In step 1, the polymer must first be heated to a temperature over T_g. In step 2, the SMP sample is processed to the desired shape at a temperature above T_g and held in its final deformed shape with a constraint. In step 3, the sample is cooled immediately below T_g, typically to room temperature. And the constraint of fixing the sample shape is removed after the completion of cooling. In step 4, the polymer is heated above T_g to recover the original undeformed shape due to the elastic energy stored during the initial deformation.

It should be noticed that recoverable force of the pre-deformed "frozen" SMP itself is ascertained as weak since the soft state of SMP resulted by the rise of temperature. Several physical properties of SMPs other than SME are also significantly altered in response to external changes in temperature and stress, particularly at the glass transition temperature of the soft segment. These properties include elastic modulus, hardness and flexibility. The elastic modulus of a SMP can be changed by a factor of up to 200 when heated above the glass transition temperature of the soft segment. In addition, the hardness of the SMP is decreased dramatically when the material is heated above its glass temperature.

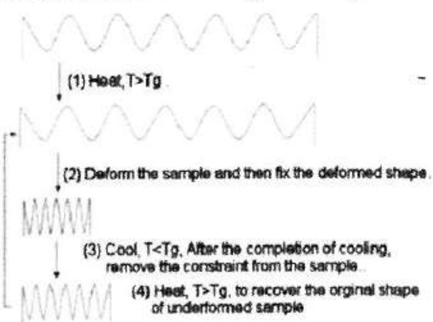

Figure 6. Schematic Draft for the Shape Recovery Cycle of SMP Samples

Figure 7 illustrates shape memory performance of SMP textile samples with uniform and densely woven SMP yarn of 0.4 mm diameter in the fabric structure. To observe the SME in the textured fabrics, the SMP composite is covered with two sheets of Aluminium foil and deformed into the shape illustrated in Figure 7 under higher temperature. The sample is then placed in a fridge under a mechanical constraint. The SMP wire recovers to its original shape of being flattened at a high temperature from being bent at a low temperature upon heating to $T > T_g$, which allows the shape of the fabric sample to vary with environmental temperature. This is because the straighten state of SMP yarn in high temperature originates from the extrusion state left from the nozzle of the extrusion machine before any shape memory training. Under the transformation temperature T_g, the bend shape of this textile is hibernated to provide a support force for the coiled state. After the specimen is heated up over the transformation temperature T_g, the hibernated SMP wire becomes soft and recovers to the original flattened shape. However, the shape memory effect is difficult to perform an invert shape variation procedure because it can only support a small recovery force when the state of SMP is varied. The problem is solved by adding some reinforcement wire of high elastic modulus to the SMP matrix when higher structural stiffness and attainable clamping force can be applied to the composites. It is expected to be support more complex shape variation while polymer fabric reinforcements of high elastic modulus cross linking with SMP yarn in a fabric structure, as demonstrated in elastic memory materials for spacecraft deployable structures [12]. Further observations in our SMP coating also confirmed that SMP layers coated on hard fabrics have stronger shape recover ability compared with single layer shape memory woven fabric due to the strong cross-linking on the fabric matrix that constitutes high elastic modulus yarns, and therefore permit more flexibility in shape memory design, which will discussed in else place in detail.

Conventional yarns of different material performance were blended and woven with SMP yarn in the samples as illustrated in Figure 8 and Figure 9. The SMP wire was woven spaciously in the weft to allow room for the SME to take place. In contrast with the sample shown in Figure 7, the composite structure freezes the fabric of being flattened state. In this case, it provides complete contraction because of the decreasing of the elastic modulus of the SMP yarn dramatically if the environmental temperature is over T_g. These shrunk fabrics may have rough and embossed edge; especially convex edges appeared in the region constituted of complete SMP yarn. The initial flat shape of these SMP composites is fixed by exerting an external stretch force when the sample is placed into a freeze state. The SME occurs similarly from being flattened at low temperature to originally rough and emboss matrix with convex edges when being contracted at high temperature. The recovery process may also be described as metamorphic in which the polymer exhibits a gradual shape variation during transformation. In contrast with that of SMA, SMP does not provide significant recovery force accompanying this triggering of smart fabrics. However, fabric design based on SMP yarn and various kinds of flexible and light yarn still can shown an interesting appealing aesthetic appeal, as shown in Figure 10. The change depends on fabric design and SMP specific training besides the external temperature.

Figure 7. Shape Memory Recovery of SMP Composite Woven Uniformly and Densely of SMP Yarn at 50 °C with Recovery Time a) 0 s, b) 15 s, c) 30 s

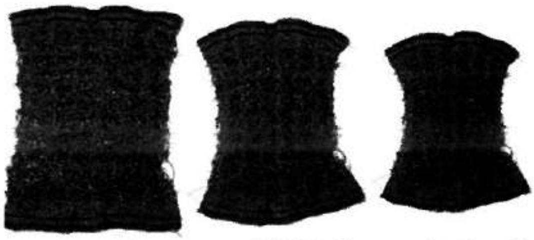

Figure 8. Shape Memory Recovery of SMP Composite Loosly Woven Fabric at 50 °C with recovery Time a) 0 s, b) 30 s, c) 60 s

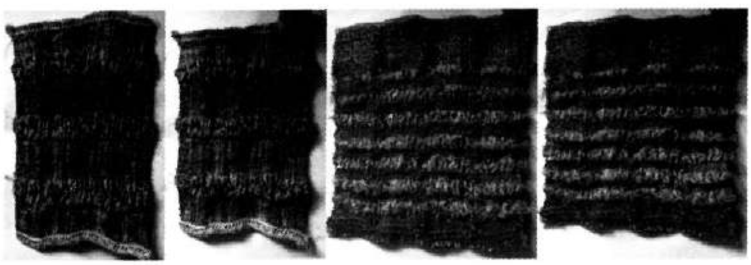

Figure 9. Shape Memory Recovery of SMP Composite Loosely Woven Fabric at 50 °C with Recovery Time a) 0 s, b) 30 s

Figure 10. Shape Memory Recovery of SMP Composite Loosely Woven with Flexible Yarn at 50 °C with Time a) 0 s, b) 30 s, c) 60 s, d) 90 s

CONCLUSION

The training procedure of SME in SMA and SMP is exploited schematically for the requirement of smart fabric design. The SME behaviour strongly depends on thermo-mechanical treatment of the materials and the cooperation of shape memory material with other flexible and rigid materials in the fabric design. Key techniques for SME training, including regulation of phase transformation temperatures in SMA, manufacture of SMP yarns, have been studied. Several fabric samples trained have shown the potential for significant shape change in response to the variation of environmental temperature. Innovative ideas have been shown and discussed, where the performance of SME can be varied in both of SMAs and SMPs.

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A Study On Comfort Characteristics Of Fabrics Made Of Specialty Fibrous Assemblies

A DAS & S M ISHTIAQUE

Comfort characteristics of plain-woven fabrics, containing viscose staple fiber twist-less and hollow fibrous assemblies and core-sheath type DREF-III yarn in weft, are reported. The twist-less and hollow fibrous assemblies are the individually separated parallel core and annular sheath components respectively of core-sheath type DREF-III yarn. In all these fabrics the same warp yarn, i.e. two-ply ring spun yarn was used. Three different types of weft yarn were prepared in DREF-III system; (i) 59 tex yarn with staple viscose fiber in both core and sheath, (ii) 118 tex yarn with staple viscose fiber in core and water soluble staple PVA fiber in sheath, and (iii) 118 tex yarn with staple PVA in core and staple viscose in sheath. The core-sheath ratio was kept 50:50% for all the DREF-III yarns. The idea is to maintain the same weft yarns count (59 tex) in all the three finished fabrics (after removal of PVA component), with different structure of fibrous assembly in weft. The structure of fibrous assemblies in weft has great impact on the comfort related properties, i.e. air permeability, thermal conductivity, percentage water vapour permeability, wicking and water absorbency.

The most important property of any apparel is comfort. Comfort is an experience that is caused by integration of impulses passed up the nerves from a variety of peripheral receptors-smell, smoothness, consistency, colour etc in the brain. Comfort is a qualitative term and it is one of the most important aspects of clothing. The clothing comfort can be divided into three groups, i.e. psychological, tactile and thermal comfort [1]. Psychological comfort is mainly related to the latest fashion trend and acceptability in the society and bears little relation to the properties of fabrics. The tactile comfort has relationship with fabric surface and mechanical properties. The thermal comfort is related to the ability of fabric to maintain the temperature of skin through transfer of heat and perspiration generated within the human body. Saville [1] distinguished two aspects of wear comfort of clothing; i) "thermo-physiological wear comfort which concerns the heat and moisture transport properties of clothing and the way that clothing helps to maintain the heat balance of the body during various levels of activity", and ii) "skin sensational wear comfort which concerns the mechanical contact of the fabric with the skin, its softness and pliability in movement and its lack of pricking, irritation and cling when damp". There is a general agreement that the transmission of air, heat and water vapour through a garment are probably the most important factors in clothing comfort. Comfort, as felt by the user, is a complex factor depending on the above attributes. Some early study [3-6] reported various aspects of comfort related properties of fabrics.

The comfort characteristics of fabrics mainly depend on the structure and types of yarn used. The development of new yarn structures raises questions about the nature and quality of fabrics made from the new yarns. Among the different yarn structures, DREF-III yarn has got typical core-sheath structure, where core and sheath components in the yarn have completely different fiber configurations. We have already reported [7] the tensile and some handle related properties having twist-less staple fiber core and the surrounding hollow sheath components individually within the fabrics. But the comfort characteristics of these types of fabrics are totally unknown. There is hardly any study in this direction.

The main objective of this study is to investigate the comfort characteristics of woven fabrics made out of staple twist-less and hollow fibrous assemblies and to compare with the characteristics of fabric with DREF-III core-sheath type of yarn. Our specific objective is to assess the ability of these types of unique structures to enhance the comfort characteristics.

EXPERIMENTAL

Three types of DREF-III yarns with different combinations of core and sheath fibres were used in weft, as given in Table 1. The fibers used for producing DREF-III yarns consisted of viscose staple fibers (44 mm long, 1.5 denier linear density, 18.8 cN/tex tenacity and 19.2% breaking elongation) and PVA staple fibers (40 mm long, 1.68 denier linear density, 41.9 cN/tex tenacity and 37.4% breaking elongation). In all the fabrics the warp yarn was same (two-ply cotton ring spun yarn with resultant count of 78.73 tex, tenacity 10.61 g/tex, breaking elongation 5.7% and initial modulus 213.19 cN/tex).

Table 1: Details of fabrics

	Grey fabric			Finished fabric[a]				
	Weft			Weft		Fabric sett, epi x ppi	Fabric weight, g/m^2	Fabric thickness, mm
Yarn type	Core/ Sheath	Core : Sheath	Count tex	Type	Count, tex			
A DREF-III	Viscose/ Viscose	50 : 50	59.0	Viscose-Viscose in core- sheath	59.0	40x39	246	0.70
B DREF-III	Viscose/ PVA	50 : 50	118.0	Viscose twist-less fibrous assembly	59.0	41 x 39	248	0.73
C DREF-III	PVA/ Viscose	50 : 50	118.0	Viscose hollow fibrous assembly	59.0	39 x 40	243	0.79

[a]After treating with hot water

Sample Preparation

All the three different core-sheath combinations of weft yarns were produced on a Fehrer AG type DREF-III friction spinning machine. The linear density of both viscose and PVA finisher draw frame slivers was maintained at 3.0 ktex. There was one sliver for core fibers and five slivers for sheath fibers. The feed rate and draft of drafting units I and II were adjusted in such a way that the core-sheath ratio become 50:50%. The spinning-drum speed and the yarn delivery speed were kept constant at 4500 rpm and 150 m/min respectively for all the samples. The count of DREF-III yarn, with 100% viscose in both core and sheath, was 59 tex. To study the behavior of fabrics with twist-less fibrous assembly in weft, the sliver with 100% viscose fiber was placed in the core (i.e. in drafting unit I) and 100% PVA slivers were placed in the sheath (i.e. in drafting unit II). When the behavior of fabric with hollow fibrous assembly in weft was studied, the placement of the viscose and PVA slivers were just reversed i.e. PVA sliver was placed in the core (i.e. in drafting unit I) and viscose slivers were placed in sheath (i.e. in drafting unit II). The linear density of these two yarns, where PVA fibers were used in sheath and core respectively, was kept exactly double, i.e. 118 tex. The idea was that to have exactly same yarn count (59 tex) in weft for all the three samples when 50% of the water-soluble PVA portion completely removed.

The plain weave fabric samples were prepared in a rapier loom using same warp yarn with identical constructional parameters. Three different types of fabrics with different types of DREF III yarn in weft were produced, as given in Table 1, i.e. Fabric A (59 tex yarn with staple viscose fiber in both core and sheath in weft), Fabric B (118 tex yarn with staple viscose fiber in core and water soluble staple PVA fiber in sheath in weft) and Fabric C (118 tex yarn with staple PVA in core and staple viscose in sheath in weft). All the three weft yarns were used one after another, so that the three fabric samples could be washed afterwards as a single piece to have similar treatment in all the fabrics. To have the staple viscose twist-less and hollow fibrous assemblies individually in weft, the PVA fibers must be removed from the sheath and core portions respectively from the weft yarn. PVA is soluble in water at 60°C, and dissolved PVA should be removed from fabric thoroughly before drying. All the three fabric samples were used as single piece and treated with hot water, using laboratory jigger, at 90°C for 2 h. Care was taken to remove the PVA portion completely. The fabric A, in which the weft yarn consisted of 100% viscose staple fibers, was also given the same treatment to normalize the effect hot water shrinkage. After complete removal of PVA fibres the fabrics B and C were having twist-less viscose fibrous assembly and hollow viscose fibrous assembly respectively in the weft. The details of finished fabric are also given in Table 1.

Testing Procedure

The linear density and tensile properties of single fiber were measured by Lenzing Vibroskop-400 and Vibrodyn-400 respectively. The end and pick densities were measured with a pick glass at ten randomly selected positions for each sample. The count of weft yarns from fabric was measured by electronic balance. Thickness of fabrics was measured at 20 g/cm^2 pressure. Shirley air permeability tester was used for measuring the air permeability of fabrics. The volume of air in cm^3 which passes per second through 1 cm^2 of fabric under head of 1 cm water-column is the measure of air-permeability. Thermal conductivity of fabrics was measured on SASMIRA thermal conductivity tester. The test specimen was placed between the heated lower plate and an insulated top plate. The time taken by the hot plate to cool down from 50^{0}C to

49^0C was measured and corresponding "Clo" value was determined from graph. The "Clo" value in turn converted to the more frequently used "Tog" value using the formula, Tog = 0.645×Clo. Higher the "Tog" value means higher the thermal resistance i.e. lower thermal conductivity. To assess the moisture transmission behaviour of fabric three different types of tests were performed, i.e. water vapour permeability, wicking and water absorbency. The water vapour permeability was measured by cup method. The specimen under test was sealed over the open mouth of a cup containing water. Evaporation takes place under standard atmospheric conditions and loss in weight of cup after 24 h was measured and then converted in terms of water vapour permeability. The water vapour permeability of the specimen was then expressed as the percentage of water vapour permeability of reference fabric (Fabric A). The wicking behaviour of fabrics was measured by suspending a strip of rectangular specimen (10" x 1") vertically with its lower edge in a reservoir of distilled water. The height of rise by water in a given time (i.e. 1 min, 3 min and 5 min) was the measure of wicking behaviour. Water absorbency is a quality of fabric to absorb water. It is a method for measuring the total amount of water that a fabric will absorb. The circular test specimen of 8 cm diameter was immersed in distilled water till it was uniformly wetted out and left overnight sandwiched between two wetted sponges. The original mass and the mass of the specimen after 24 h was recorder. The absorption is mass of water absorbed expressed as the percentage of original mass of specimen.

RESULTS AND DISCUSSION

All the comfort related properties (air permeability, thermal conductivity, percentage water vapour permeability, wicking height and water absorbency) of the fabrics are shown in Table 2.

Air permeability

It is clear from the Table 2 that the fabric B (with twist-less fibre assembly in weft) had highest air permeability where as the fabric C (with hollow fibre assembly in weft) had the lowest. Diameter, structure and crimp of yarn and flattening of fibrous structure affect the air permeability of a fabric. The very low air permeability of fabric C may be attributed due to very bulky structure of hollow fibrous assembly in weft resulted in blocking the inter yarn spaces. For same count of weft (59 tex) the effective diameter of hollow fibrous assembly (sheath component) was higher as compared to the twist-less fibrous assembly (core component) and normal core-sheath type DREF-III yarn. Blocking of inter yarn spaces may also be due to partial flattening of hollow structure after removal of core component [8] resulted in reduction of air permeability. The twist-less fibrous assembly and the DREF-III yarn in the weft resulted comparatively higher inter yarn space due to their compact packing which in turn resulted higher air permeability than fabric C.

Thermal conductivity

It is evident from the Table 2 that fabric A showed the maximum thermal conductivity and fabric C (with hollow fibrous assembly in weft) showed minimum thermal conductivity values. The fabric B (with twist-less fibrous assembly in weft) had intermediate thermal conductivity value. The minimum thermal conductivity of fabric C may be attributed due to very bulky structure of hollow fibrous assembly in weft works as an insulating medium. It entrapped air in the hollow spaces and does not allow heat of inner layer to transmit to outer layer. On the other hand fabric B with twist-less fibrous assembly, with flattened structure, resulted more barrier to the heat transfer than fabric A. The relatively open structure of fabric A resulted higher thermal conductivity through it by convection and radiation.

Water vapour permeability

Water vapour permeability is an important parameter in evaluating comfort characteristics of a fabric, as it represents ability to transfer perspiration coming out of the body. Table 2 shows that the fabric C had highest water vapour permeability where as the fabric B had the lowest value and the fabric made out of core-sheath type DREF-III yarn (fabric A) having intermediate water vapour permeability value. The very high water vapour permeability value of fabric C (with hollow fibrous assembly in weft) may be attributed due to very bulky structure of hollow fibrous assembly in weft. Yarn character plays important role in transmission of water vapour. Open structure allows more water transmission. Hollow yarns have better cover factor which allows water vapour to transfer from inside to outside through diffusion. When the transmission occurs through pores the rate is independent of water vapour concentration. A larger amount of liquid mass can be retained in larger pores, which facilitates the diffusion process from inner layer to outer layer. Where as small pores of fabric B retained less amount of water mass in fabric resulting lower water vapour permeability.

Table 2: Comfort related properties of fabrics

Sample	Air permeability, cc/sec/cm^2	Thermal conductivity, tog	Water vapour permeability, %	Wicking height, cm						Water absor-bency, %
min				Warp 1 min	3 min	5 min	Weft 1 min	3 min	5	
Fabric A	48.67	0.3225	100.0	1.2	2.8	3.6	1.4	2.7	3.6	136.04
Fabric B	53.00	0.5015	94.8	1.0	2.9	3.4	4.9	6.8	8.7	129.23
Fabric C	13.23	0.6950	107.4	1.2	2.9	3.7	3.2	5.5	6.4	142.53

Wicking

Wicking property of a fabric mainly depends on characteristics of fibre and structure of component yarns and the fabric. Table 2 shows the wicking height of fabrics in warp and weft directions for different time duration. It can be seen from the table that the fabric B has highest wicking value in weft direction followed by fabric C and the fabric A shows lowest wicking in weft direction. The warp way wicking for all the fabrics are almost same which may be due to same warp yarn for all the three fabrics. Wicking can only occur when fibers assembled with capillary spaces between them when wetted by a liquid. Capillary forces are responsible to drive the liquid in capillary spaces. The fiber surface properties and pore structure are the main determinants of wicking properties. The capillary principle dictates that smaller pores are filled first and are responsible for the front movement of the liquid. As the smaller pores are completely filled, the liquid then moves to the larger pores. The size and spaces of fibers as well as their alignment will influence the topology of the inter-fiber spaces or pores, which are channeled with widely varying shape and size distributions. The fabric B has twist-less and parallel-channeled fibrous assembly in weft. The twist-less fibrous assembly due to more parallel fibers, small pores and channels absorb more water through capillary pressure. Small, uniformly distributed and inter-connected pores and channels facilitate fast liquid transport. The wicking height increases with the time for all the fabrics, as evident form Table 2.

Water absorbency

The water absorbency of a fabric mainly depends on the moisture regain of component fibre and open space within the fabric structure and is an indication of sweat holding capacity of the fabric. The fibre components in all the three fabrics are exactly same, so the amount of voids within the structure of fabric plays an important role in water absorbency. It is clear from the Table 2 that the fabric C has highest water absorbency where as the fabric B has lowest water absorbency. The very high value of fabric C may be attributed due to very bulky structure of hollow fibrous assembly in weft. The water replaced the air in hollow fibrous assembly and thus it can hold more water. On the other hand fabric B shows least water absorbency value, which may be due to compact and parallely aligned twist-less fibrous assembly does not have sufficient open space to hold extra water. The fabric made out of core-sheath type DREF-III yarn having intermediate water absorbency value.

CONCLUSIONS

The fabric with twist-less fibrous assembly in weft shows highest air-permeability, whereas the fabric with hollow fibrous assembly in weft resulted lowest air-permeability.

Thermal resistance of fabric with hollow fibrous assembly in weft is found to be higher than the fabric with twist-less fibrous assembly in weft. The fabric with core-sheath type DREF-III yarn in weft shows least thermal resistance.

The water vapour permeability of fabric with hollow fibrous assembly in weft is found to be higher than other two types of fabrics. The fabric with twist-less fibrous assembly in weft shows least water vapour permeability.

The weft wise wickability of fabric with twist-less fibrous assembly in weft is highest, followed by the fabric with hollow fibrous assembly in weft and the fabric with core-sheath type DREF-III yarn in weft has least wicking property.

The fabric with hollow fibrous assembly in weft shows highest water absorbency, whereas the fabric with twist-less fibrous assembly in weft has the least value.

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Textile Materials And Products For Activewear And Sportswear

SC ANAND & L HIGGINS

According to Textile Intelligence[1] estimates, worldwide sales of activewear and sportswear increased by 23% between 1997 and 2001. In the European Union, the market for sports apparel and equipment is now worth over Euro 37 bn (US$ 43 bn) and in the USA sales are estimated at around US$ 46 bn[1].

The dramatic growth in activewear and sportswear market has significant implications for the textile industry. Spending in the UK alone exceeded £4 billion in 2002 and is predicted to reach £5 billion in 2007. The sector ranges from specialist apparel for specific sports to sportswear worn for its fashion value. Different sports require garments to fulfil different functions. For example wind proofing and high thermal insulation are required for skiwear, whereas efficient thermoregulation and moisture management are required in football shirts.

The paper discusses the textile materials and products specifically designed for activewear and sportswear. It discusses fibres, yarns, fabric structures and fabric finishes currently used to enhance comfort in the wearer during strenuous exercise. The testing, analysis and benchmarking of sportswear structures will be discussed for specific test methods used for a wide range of sportswear and activewear garments developed at Bolton Institute.

The dramatic growth in the activewear and sportswear sector has significant implications for the textile industry worldwide. According to Pierre Duffar, DuPont's European active sportswear manager, worldwide sales in this sector increased by 75% between 1987 and 1998. He anticipated growth of 23% between 1997 and 2001. Sales within the European EU15 market are currently worth at least £16 billion with £11 billion being spent on sports clothing. A recent Key Note report estimated that, in 2002, UK consumers spent £4.05 billion on sportswear. The report estimated that £2.9 billion was spent on clothing and £1.15 billion on footwear. This represents 10.3% of the total clothing and footwear market. Table 1 illustrates the total UK sportswear market since 1998.The sector includes specialist apparel for specific sports each with its own particular functions. The performance fibres, yarns, fabrics and finishes developed for this specialist sector are increasingly transferring to the mass market in the high street. The increasing cultural importance of sportswear in fashion meant that only 25% of sportswear was used for active sports or during exercise. In the report, Key Note forecast a 17.6% growth in the sportswear market over the next five years resulting in UK sales of £5 billion in 2007.

Consumers demand high levels of comfort, design and easy care in all types of clothing. However, in sportswear, where thermophysiological comfort can significantly enhance the performance of the wearer, the use of innovative textile products and materials is increasingly common.

Table 1: Total UK Sports Clothing and Footwear Market at Current Prices (Source: Key Note)

	1998	1999	2000	2001	2002 (est)	% change 1998-2002	% change 1999-2002
Sports clothing (£ billion)	2.63	2.55	2.65	2.75	2.90	10.5	13.7
Sports footwear (£ billion)	1.20	1.15	1.20	1.20	1.15	-4.2	0.0
Total (£ billion)	**3.83**	**3.70**	**3.85**	**3.95**	**4.05**	**5.9**	**9.5**

What Is Comfort?

For the consumer the comfort of any garment stems from a combination of its sensorial properties, its psychological properties and its thermophysiological properties. Comfort is determined by the interaction of the body, its microclimate and its clothing. Where garments are worn as layers, it is a combination of the properties of the individual garments that determine the comfort of the whole clothing system.

Whilst undergoing strenuous activity a body generates additional metabolic heat. Sweat is produced as part of the natural mechanism for the dispersion of that heat. A naked man can control his heat loss almost instantly as sweat is evaporated very quickly during the period of activity leaving no accumulated sweat when activity stops. Clothing can act as a barrier to heat and moisture loss. If over-heating is to be avoided, thermoregulation and moisture management are key functions of clothing designed for use as sportswear or activewear. For sportswear that has transferred to the mass market and may be worn on a daily basis, such as football and rugby shirts, the psychological and sensorial functions are as important as the thermophysiological properties.

Psychological comfort consists of a combination of consumer prejudice and prevalent fashion trends. Where garments are worn during strenuous activity, psychological comfort also occurs when the garment is extensible and does not restrict mobility. A garment with low intrinsic weight can significantly aid sporting performance. Colour and shape retention over multiple wash/wear cycles are a further prerequisite for success in the mass market.

Sensorial comfort is focussed on the tactile sensation of a garment on the human body. Garments should be soft and pliable during wear and, especially when damp, should not prickle / irritate or cling to the body. To a lesser extent, sensorial comfort can be improved by the control of odour and by use of UV resistant materials. Waterproofing can improve sensorial comfort but may impair thermophysiological comfort.

Thermophysiological comfort entails both thermoregulation and moisture management. Garments should be designed to maintain the human body temperature and moisture output close to its normal levels under diverse conditions. The thicker the layer of air trapped inside the clothing system the greater its thermal resistance and its resistance to moisture transmission. If perspiration is trapped next to the skin during exercise it can lead to an increase in body temperature; this will cause dehydration, fatigue and decreased performance. The thermal insulation properties of a fabric usually decline when the fabric is wet resulting in rapid heat loss from the wearer. This wetting can occur both from outside a garment (rain) and from inside a garment (perspiration). During strenuous activity wet fabric can aid in the cooling of the hot skin surface. However, once the activity and the excessive heat production stop, this heat loss must be restricted. A wet body cools very quickly leading to post-exercise 'chill' or, in extreme cases, hypothermia.

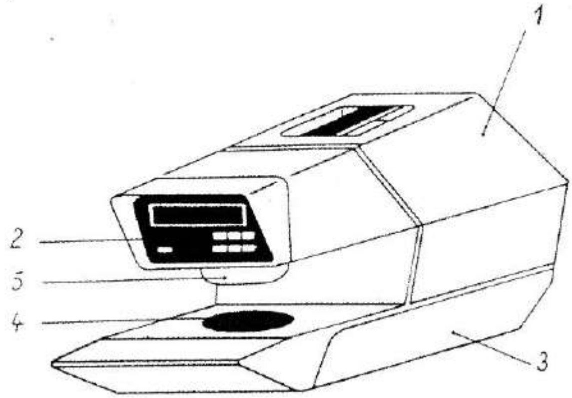
Garments that are designed for sportswear and activewear should be dynamic or responsive. Through effective thermoregulation and moisture management a clothing system can maximise heat loss when the wearer is hot then increase thermal insulation when perspiration stops. In a sports arena dynamic or responsive garments can enhance performance, control weight build up in clothing and reduce the potential for skin damage.

TEST METHODS USED TO MEASURE THERMOPHYSIOLOGICAL COMFORT

Various test methods exist for the measurement of comfort properties. BS 4745 uses either a two plate togmeter or a single plate togmeter to measure thermal conductivity. ASTM D1518 uses a guarded hot plate method to measure thermal transmittance. Water vapour permeability can be measured using the cup method as defined in BS 7209 and in ASTM E96-80. Alternatively moisture vapour permeability can be determined using a sweating guarded hotplate method in which a plate is heated to skin temperature and supplied with water in order to simulate sweating. Absorption and wicking are typically measured separately. Absorption is measured by a static immersion test as defined in BS 3449. The wicking test suspends a strip of fabric vertically with its lower edge in a reservoir of distilled water. The rate of rise of the leading edge of the water is monitored. Transverse wicking can be determined using a plate test, The test methods currently used at Bolton Institute, UK, to determine comfort are described below.

Alambeta instrument, developed by Sensora, Czech Republic, determines a number of thermal transmission parameters. The instrument, shown in Figure 1, measures the behaviour of the heat that flows through the test material due to the different temperatures of the lower measuring body and the heated measuring head. Measurements do not include the layer of air associated with fabric during actual use. Alambeta is used to measure fabric thickness, thermal conductivity, thermal diffusivity and thermal resistance. It also measures thermal absorptivity ($W\,m^{-2}\,s^{1/2}\,K^{-1}$), which Sensora define as the warm cool feeling at the first contact of the human skin with a textile fabric. All five above mentioned properties can be determined in dry and wet state fabrics.

Permetest instrument, also developed by Sensora, determines the relative water vapour permeability, that is the percentage of water vapour transmitted through the fabric sample compared with that through the equivalent thickness of air. It also measures the resistance to evaporative heat loss of a fabric with its associated layer of air. The apparatus consists of a heated porous membrane, which is used to simulate sweating skin. A current of air passing over the plate can be controlled to simulate the effect of different wind speeds. The heat required to evaporate the water from the membrane with and without a fabric covering is measured. The results are automatically recorded on an ink recorder attached to the instrument.



Combined Wicking and Absorption Apparatus was developed at Bolton Institute, UK, to measure concurrent absorption and wicking. Traditional methods measure absorption horizontally and wicking vertically. This new method, illustrated in Figure 2, determines the mode of water transport through the fabrics that is not evidenced by separate tests. The method simulates the absorption of sweat by a garment from a profusely sweating body and its transport across the fabric surface. Initial uptake of water is through absorption in a direction perpendicular to the fabric plane over an area of 23.75 cm^2. Wicking starts as soon as the area under the plate is saturated. This computerised instrument is highly reproducible and determines the absorption and wicking capacity and rate. The results are graphically illustrated by the computer.

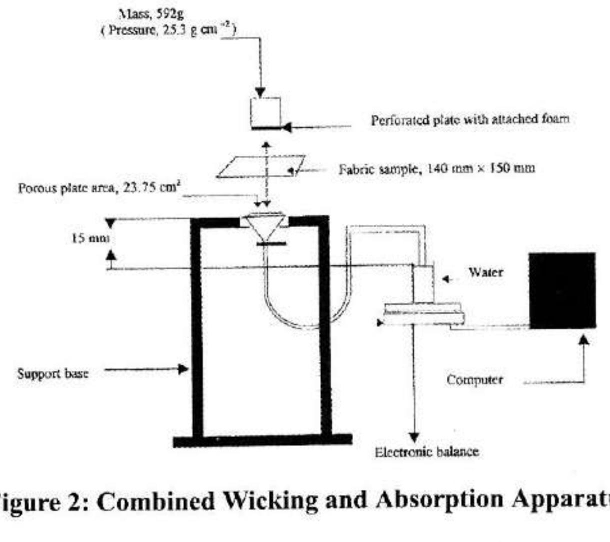


Figure 2: Combined Wicking and Absorption Apparatus

Properties Relevant To The Measurement Of Comfort

For sportswear and activewear the properties most relevant to the measurement of comfort are those related to thermoregulation and moisture management. These are listed first followed by those properties relevant to sensorial comfort.

Intrinsic thermal insulation (units = m^2 °C W^{-1}, or m^2 K W^{-1}, or Tog = 0.1 m^2 °C W^{-1}, or Clo = 0.155 m^2 °C W^{-1}) measures the resistance of a fabric to dry or conductive heat loss. Intrinsic thermal resistance can be measured in a dry or damp fabric. It is generally proportional to fabric thickness. Intrinsic thermal insulation does not include the effect of the layer of air associated with a fabric during actual use.

Thermal insulation (units = m^2 °C W^{-1}, or m^2 K W^{-1}, or Tog = 0.1 m^2 °C W^{-1}, or Clo = 0.155 m^2 °C W^{-1}) measures the resistance of a fabric and its associated layer of air to dry or conductive heat loss. Thermal insulation, unlike intrinsic thermal insulation, will vary with wind speed. Increasing wind speeds decrease the thermal insulation afforded by the layer of air.

Resistance to evaporative heat loss of a fabric with its associated layer of air (units = =m^2 mm Hg W^{-1} or m^2 Pa W^{-1}) determines the resistance of fabric to the cooling of the body through evaporation of heat generated during activity. This can also be measured on dry or damp fabrics.

Thermal conductivity of fabric determines the rate of transmission of heat through a fabric. Thermal conductivity is the reciprocal of thermal insulation or resistance.

Moisture vapour permeability (units = g m^{-2} hr^{-1}) determines the resistance of a fabric to the transfer of water vapour or insensible perspiration emanating from the body. Relative moisture vapour permeability (%) determines the percentage of water vapour transmitted through the fabric sample compared with that through the equivalent thickness of air. An increase in fabric thickness tends to lead to a decrease in the rate of water vapour transmission through the fabric. Low moisture vapour permeability prevents perspiration from passing through the fabric leading to a precipitation and accumulation of sweat in the clothing.

Water (sweat) absorption determines the capacity (units = g m^{-2} or g g^{-1}) and rate (units = g m^{-2} s^{-1}) of a fabric to mop up the liquid sweat generated by the body. Ideally the absorption capacity should be low at the surface of the fabric in contact with the skin to prevent wet clinging.

Wicking determines the capacity (units = g m^{-2} or g cm) and rate (units = g m^{-2} s^{-1}) of a fabric to transport absorbed sweat away from the point of absorption, that is away from the skin.

Air permeability (units = cm^3 cm^{-2} s^{-1} @ 10 mm Hg) determines how well air can flow through a fabric. It can be measured in dry or damp fabrics and will be expected to reduce in fabrics where absorption of water leads to fibre and yarn swelling. Air resistance is the reciprocal of air permeability. Air permeability doesn't always equate to good moisture vapour permeability.

Rate of drying (units = g m^{-2} s^{-1}) from the outer surface of a fabric must be optimal for continuous wicking and hence prevention of saturation of the fabric with sweat.

Wind proofing a garment provides a mechanism by which heat loss by convection is reduced thereby improving the thermal insulation properties of the clothing system.

Surface coefficient of friction of a fabric contributes to the sensorial comfort of a fabric. The coefficient can increase significantly in a wet fabric leading to rubbing or chafing of the skin. Low surface coefficient of friction is essential where one layer of fabric must move freely against another layer of fabric.

Handle of a garment describes its tactile qualities and includes softness, compressibility, pliability, drape etc. These properties, though less important in specialized sportswear than in clothing worn on a daily basis, should not impair the performance of the wearer.

UV resistance is important in clothing worn under high levels of exposure to the sun. It is particularly important in skiwear where the wearer is less aware of exposure.

Anti-microbial / anti-bacteria / anti-odour properties are particularly important in items such as sports socks, underwear etc. which are worn, and are in contact with sweat, for long periods of time.

Heat Loss From The Clothing Of A Person Carrying Out Strenuous Activity

The optimal conditions for comfort as measured at the skin's surface are 31.5 32.5 °C and 60% relative humidity in a static environment and 33.5 34.5 °C and 70% relative humidity in a dynamic environment. When a person is involved in strenuous activity the additional metabolic heat produced can be dissipated by conduction, convection and radiation, as well as by evaporation.

Conduction of heat from the body occurs through direct contact with clothing and is determined by the difference in temperature of the two substances and by their thermal conductivities.

Convection occurs when air, in contact with the body, is heated by conduction and then carried away from the body by convection. Convection losses can be reduced by restricting the movement of air close to the body.

Radiation transfers heat by use of electromagnetic waves. Hot objects radiate heat to the surrounding cooler environment. Radiated heat loss, although significant in a naked body at rest, can largely be ignored as a mechanism for heat loss in a clothed body during activity. However the effect of colour on radiation absorption will be influential in clothing with black clothes being the best absorbers and radiators of heat.

Evaporation uses large quantities of heat taken from the skin to change liquid sweat into vapour hence reducing the temperature of the skin. Sweating alone does not remove heat from the body; rather it is the evaporation of this sweat that causes heat loss.

The prevailing method of heat loss will depend on environmental conditions. During strenuous activity where environment temperature, that is the temperature of the air in the vicinity of the skin, approaches skin temperature heat loss through convection and radiation become insignificant. Hence heat loss by evaporation and heat loss by conduction are the two mechanisms that influence thermophysiological comfort during exercise. Clothing acts to change heat loss by changing both the heat lost through conductivity and by restricting the transport of moisture vapour away from the skin, thereby restricting heat loss by evaporation.

Total heat loss from a clothed person undertaking strenuous activity will equal the conductive dry heat loss plus the evaporative heat loss through the clothing with its associated layer of air.

$$\text{Dry heat loss } (H_d) = (T_s \;\; T_a) / R_c$$

Where H_d = rate of dry or conductive heat loss ($W\ m^{-2}$)
T_a = ambient temperature (°C)
T_s = skin temperature (°C)
R_c = thermal insulation of clothing plus associated air ($m^2\ °C\ W^{-1}$)

$$\text{Evaporative heat loss } (H_e) = (p_s \;\; p_a) / R_e$$

Where H_e = rate of evaporative heat loss ($W\ m^{-2}$)
p_s = moisture vapour pressure at skin surface (mm Hg)
P_a = moisture vapour pressure of ambient air (mm Hg)
R_e = resistance to evaporative heat transfer of clothing plus associated air (m^2 mm Hg W^{-1})

Therefore total heat loss $H = (T_s \;\; T_a) / R_c + (p_s \;\; p_a) / R_e$

Where more than one layer of clothing is worn the total heat loss will depend on the individual garments and on the layers of air trapped within the clothing system. If the layers are sufficiently tight fitting so that heat is not lost by convection then the total heat loss will be a function of the summation of the thermal insulation values for the individual layers.

Water Absorption And Wicking

Each unit quantity of sweat evaporated from skin removes a quantity of heat from the body as determined by the latent heat of evaporation. Man can secrete sufficient sweat to maintain body temperature within a limited range during strenuous activity so long as that sweat is evaporated. When wearing clothes the ability of the exercising body to lose heat will depend on the ability of the clothing system to draw sweat away from the skin and to facilitate rapid evaporation of that sweat from the outer surface of the clothing.

Moisture is transmitted through clothing by diffusion of insensible perspiration as a vapour through the fabric and, as the amount of sweat produced increases, by wicking of liquid perspiration away from the skin.

Diffusion of water vapour through the fabric occurs through the air gaps between the yarns. It is largely determined by fabric structure. Moisture vapour permeability is a measure of the fabric's ability to allow moisture vapour to pass through it. Fabrics with low moisture vapour permeability lead to an accumulation of sweat in the clothing and hence impaired thermophysiological comfort. Fabrics that have been coated to make them waterproof are most likely to have low permeability. Hence waterproof breathable fabrics have been developed in which membrane pore size at the outer surface of the fabric or weave tightness is controlled such that water vapour (0.0004 μm) can pass through but water droplets (100 μm) cannot. Another mechanism for improving moisture vapour permeability is to use a hydrophilic film in which moisture can be absorbed and transported to the outer surface of the fabric by diffusion.

As with thermal insulation, the moisture vapour permeability of a multi-layered clothing system is dependent on the moisture vapour permeabilities of the individual layers with their associated air gaps. Where the clothing system impedes the transport of moisture vapour it will accumulate and precipitate in the fabric that has the greatest moisture vapour permeability. This is often the layer worn against the skin leading to wetness and rapid loss of heat when exercise stops.

Wicking of moisture within textiles is similar to the wicking of water through capillaries. The spaces between fibres act as capillaries. The smaller the diameter of those capillaries, that is the less space between the fibres, and the greater the surface energy of the fibres the greater the capillary action. However this capillary action stops when a fabric is saturated with water or sweat. In order to continually draw sweat away from the skin a moisture differential must be maintained between the inside and outside surface of the fabric. Hydrophilic fibres have a high surface energy and pick up moisture more readily than hydrophobic fibres which have low surface energies. The use of a hydrophobic fibre against the skin with a hydrophilic fibre on the outer surface of a fabric is a common combination used to pull the moisture through the fabric.

The capillary network within a fabric will vary in different directions within that fabric. Different rates of wicking will be seen through the thickness of the fabric compared to that in the plane of the fabric. It should also be noted that in fabrics where fibres absorb water, the fibres and yarns may swell as water is absorbed thereby changing the rate of wicking.

Fibres And Constructions For Activewear And Sportswear

The properties of any given fabric are determined by the inter-relationship and interactions of the properties of its constituent fibre(s), its yarn(s) structure, its fabric structure and the chemicals, finishes or membranes etc. used during manufacture. The thermophysiological comfort of an individual garment cannot be defined in terms of the moisture properties and heat transfer behaviour of its constituent fibres alone as the dissipation of heat and moisture will be determined by geometry and packing density of the fibre, yarn and fabric structure, as well as the type and method of application of various finishes and / or coatings. Whereas fabrics made from natural fibres such as cotton are considered very comfortable for use under normal conditions, their properties make them unsuitable for use during strenuous activity.

Natural Fibres

Cotton can absorb high levels of moisture leading to a feeling of wetness and cling. However it has a very slow wicking rate from the inner to the outer surface of a fabric. This makes cotton an unsuitable fibre for use against the skin during strenuous activity. Wetness, accompanied by a very slow rate of drying, can also lead to rapid and undesired heat loss once activity stops. Moisture absorbency can also lead to a significant increase in the weight of the garment which may further impair sporting performance. However cotton fabrics are easier to clean than polyester and other manufactured fibres and tightly woven cotton fabrics provide a degree of water resistance in outerwear.

Wool has good wicking ability and is a good insulator even when wet. Wool fibres have the highest moisture regain of all fibres at a given temperature and relative humidity. The fibres have a natural water repellence in gentle or misty rain which aids both thermophysiological and sensorial comfort. However wool is slow to dry and has a high wet surface coefficient of friction leading to potential skin abrasion.

Silk is a soft and strong natural filament with a luxurious handle. It has good wicking ability and can absorb water up to one-third its weight without feeling wet. Silk has high thermal conductivity and feels cool to the touch. Silk however is not an easy care fibre which is a disadvantage in sportswear that is worn regularly.

Polylactic acid or PLA is a new fibre developed and marketed by Cargill-Dow, USA. It is based on cornstarch and combines hydrophilicity with good resilience. PLA fibres also possess many biomedical properties, such as anti-microbial or anti-bacterial properties.

Regenerated Cellulose Fibres

Viscose rayon is made from 100% cellulose like cotton but has a higher proportion of amorphous material. It is more absorbent than cotton allowing viscose to absorb insensible perspiration without producing wet cling. The irregular surface of viscose fibres contributes to comfort when worn against the skin. However these fabrics are difficult to launder making them less suitable for use during strenuous activity.

Lyocell is created through an environmentally friendly solvent-spun process. The fibres have perfectly round cross sections and a smooth surface. Lyocell fabrics have the comfort properties normally associated with cellulosic fibres with the added advantage of high tensile and tearing strengths. An example of lyocell is Tencel by Acordis UK Ltd.

Synthetic Fibres

Polyester is the single most popular and common fibre used in activewear and sportswear. In its unfinished state polyester is hydrophobic, it has a very low absorption capacity and rate compared with cotton. However its wicking rate is faster than that of cotton albeit still slow. It is also cheap to manufacture and considered easy care. It possesses excellent washing and wearing properties. Where polyester is used against the skin it is generally treated to improve its wicking ability. This can be achieved by applying a hydrophilic coating to a polyester filament. With a hydrophobic core and a hydrophilic surface moisture will migrate along the outer surface of the filament without absorbing moisture. However these coatings are not durable to long term laundering. An alternative method is to change the surface chemistry of the polyester filament by molecular modification. This method is more expensive but it has the advantage of being permanent. Any finish which increases hydrophilicity also increases the ability of the fabric to release soil. Fabrics made from polyester are exceptionally durable to mechanical and chemical degradation during repeated wash/wear cycles. Some special type and shape, as well as modifications of polyester fibres are discussed separately in this review.

Polyamide fibres such as Nylon 6 and Nylon 6,6 have higher moisture absorption capability than polyester, have better wicking ability but have a slower drying rate. Polyamide fibres are exceptionally strong fibres with high abrasion resistance, and high flexibility and elasticity. They are relatively more expensive than polyester and hence their use tends to be restricted to swimwear or cycling wear or as a reinforcing fibre in blends in sports socks. When polyamide fibres are used in a tightly woven fabric they have very low air permeability making them an ideal light-weight material for windbreaker jackets and for the outer shell of ski garments. However, the low moisture vapour permeability of such fabrics mean they can be uncomfortable when worn against the skin. There are also a number of variants available in polyamide fibres, such as anti-microbial, high wicking, extra soft etc.

Polypropylene fibres are increasingly being used in the sportswear market although its market share is still very small. The fibres have very low moisture absorbency but excellent moisture vapour permeability and wicking capabilities. Insensible and liquid perspiration are transported away from the skin without being absorbed making it an ideal fibre for sportswear. As polypropylene does not become wet its thermal insulation is retained during and after strenuous activity. Polypropylene is also a very light weight fibre and, unlike polyester, does not produce static. However soil removal is difficult and fabrics made from polypropylene may shrink if washed at high temperatures. These fibres are also relatively more difficult to dye and finish.

Acrylic fibres are generally only used in sportswear and activewear in the form of high pile fleece fabrics. Acrylic fibres are crimped creating bulky fabrics with good thermal insulation. They have low water absorbency but will wick liquid sweat. They are also lightweight however acrylic fabrics are prone to static build up and have a tendency to pill during wear.

Elastomeric fibres such as spandex are generally used in small quantities in a garment to significantly increase stretch and to increase support. Swimwear may contain 15 40% of elastomeric fibre with knitted sportswear containing 3 10%. Consumers commonly know spandex as Lycra®, manufactured by DuPont, and Glospan® and Cleerspan® manufactured by Globe Manufacturing. Elastomeric fibres do not add to the thermophysiological comfort of the garment in which they are incorporated.

Specialised Fibres

Synthetic fibres can be adapted during manufacture to improve their thermophysiological and sensorial properties. Many different techniques exist; additional substances or block polymers can be added to the base polymer before extrusion; fibres can be extruded with different cross sections; and fibres can be coated. One of the most common adaptations for improved comfort is the use of microfibres with linear densities of much less than 1dtex per filament. Super fine fibres or microfibres enable very dense fabrics to be created in which the fibre surface area is significantly increased and the space between the fibres reduced. This acts to increase capillary action leading to better thermoregulation.

Polyester based specialist fibres have been developed in order to achieve a more natural handle, to increase absorbency, to provide better thermal resistance and to reduce static. The introduction of voids within polyester fibre has been used to improve wicking and to improve thermal resistance. Welkey® by Teijin Ltd. is a fibre, used in sportswear, with a hollow core and a proliferation of smaller holes throughout the body of the fibre thus increasing capillary action and the wicking of sweat away from the skin. The increased air spaces within the fibre also increase the thermal resistance of the fibre.

Coolmax® by DuPont is a tetra-channel polyester fibre with a cross section like a double scallop (Figure 3). This fibre was produced specifically for the sportswear market. It has improved wicking capability and moisture vapour permeability. As can be seen from Figure 4 CoolMax® dried significantly faster than other fabrics regularly used in sportswear.

DuPont also developed Thermalite® for use in cold weather conditions. Thermalite® is a very fine hollow core fibre. The presence of air in the fibre core significantly improves the thermal resistance of the fabric. The convoluted surface of these fibres and the increase in surface air generated by using a fine fibre improve the wicking capacity and rate of the fabric. The fibres are also crimped in order to further increase the insulation properties of Thermalite® fabrics. Thermalite® Base is particularly suitable for use against the skin

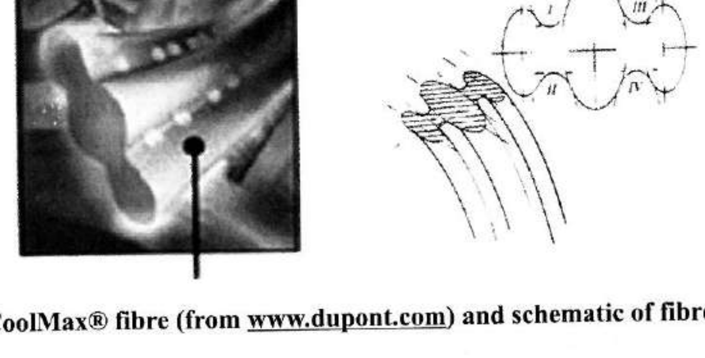


Figure 3: CoolMax® fibre (from www.dupont.com) and schematic of fibre cross section

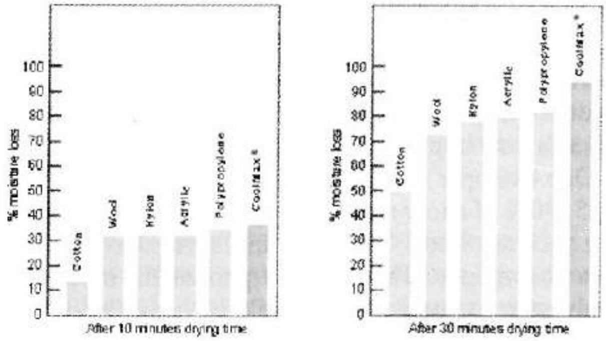


Figure 4: Fabric Drying Rates of CoolMax® vs. Other Fabrics (from www.dupont.com)

The use of polyester microfibres has been wide spread in sportswear. They are often used in outerwear. If treated with a fluorocarbon finish these fabrics have a high resistance to water penetration whilst being permeable to moisture vapour. These fabrics combine improved handle with strength and durability. Examples include Trevira® Finesse® by Hoechst Celanese based on the pentalobal Trevira® fibre and Fortel® MicroSpun® by Fiber Industries.

Polyamide based specialist fibres include Hydrofil® by Allied Signal Inc. which is a polyamide co-block polymer containing 85% nylon 6 and 15% polyethylene oxide diamine. This process significantly improves water absorbency up to the levels found in cellulosic fibres.

An example of a fibre with an altered cross section is that used in Tactel® by DuPont. Tactel® is a fabric made from fine nylon 6,6 filaments with trilobal cross sections which have been air-jet textured giving a softer, more natural handle. The method of incorporating these filaments into yarns and fabrics determine the properties of the final product (Figure 5). Polyamide microfibres such as Tactel® Micro®, Microfine® and Supplex® Microfiber® by DuPont are used in fabrics to produce superior wind protection, a soft feel and good moisture vapour transmission away from the skin.

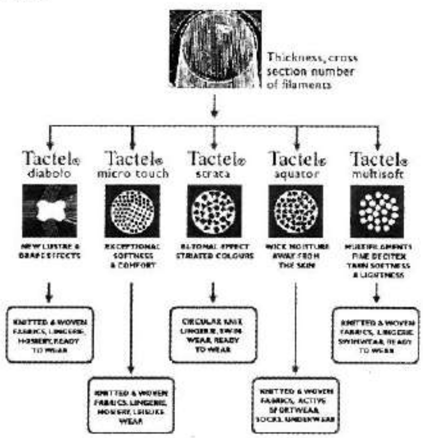


Figure 5: How Tactel ® is made (from www.dupont.com)

Fibre Blends

By blending two or more fibres in one yarn it is possible to improve the thermophysiological properties of the individual components. Knitted fabrics made from polyester/wool blends or polypropylene/wool blends can improve wicking and insulation properties within a single layer fabric structure. One example are the DriRelease® yarns made by Optimer which are made from a blend of 85 90% of a low moisture absorber such as polyester, and 10 15% of a hydrophilic staple fibre such as cotton. The resultant fabrics have a soft handle, are wettable and wick but have low absorbency. The effect is permanent unlike some of the chemical finishes applied to polyester to improve its wicking capacity. DriRelease® fabrics dry substantially faster than cotton fabrics although slower than fabrics made from Coolmax®.

By blending synthetic and natural fibres other performance properties can be incorporated such using anti-odour or anti-microbial additives in the synthetic component.

Another example of a blended-fibre performance fabric is Damart fabric made from 85% PVC and 15% acrylic fibres in blended yarns. These fabrics are extensively used as thermal fabrics for a wide range of apparel products.

Yarns

Fabrics made from staple-fibre yarns are more absorbent than fabrics made from filament yarns of the same fibre content and yarn size due to the looser packing of the yarn. Looser packing increases the fibre surface area for absorption and, by increasing the gaps between the yarns, increases moisture vapour permeability. Staple-fibre yarns also provide better thermal insulation due to the increased volume of air contained in the yarn. They may also improve sensorial comfort by feeling warmer to the touch; the yarns have slightly lower areas of contact with the skin. Crimping of synthetic yarns can improve water vapour permeability by decreasing close packing of the fibres in yarns and yarns in fabrics thus improving thermophysiological comfort. However staple-fibre yarns do not shed soil as well as filament yarns and they have a greater tendency to pill or shed lint. Filament yarns are used in windbreaker jackets and in the shell and lining of skiwear where a combination of dense weave and low surface coefficient of friction are desirable.

Fabric Structures

In general knitted fabrics provide better extensibility and recovery, shape retention and better vapour transmission than woven fabrics making them a good base for sportswear. Fabrics with fuzzy surfaces, such as knitted fabrics, feel warmer than smooth surfaced, woven, fabrics of the same fibre composition due to the decreased contact with the skin.

The effect of different warp knitted structures on thermophysiological comfort can be seen in Table 2. In this instance the same yarn was used throughout. The most open construction, 3D Eyelet, was also the thinnest. It provided the best moisture vapour permeability but poor thermal insulation. It will be observed from Table 2 that the Micromesh structure, which has much smaller openings or holes than the 3D Eyelet structure, but is relatively more open than the Pique and Mock Rib structures, yielded the most favourable combination of comfort properties. It has a reasonable thermal insulation, the least resistance to evaporative heat loss and a good water vapour permeability. These results demonstrate that the fabric structure is a dominant factor in the design of sportswear garments.

Multi-layer fabrics, produced by using both warp and weft knitting technology, have been designed for use in sportswear and activewear. A simple two-layer construction can be knitted in which the inner layer is made of a textured synthetic filament yarn which is hydrophobic and has good capillary action. The outer layer, made from a hydrophilic yarn, absorbs the wicked moisture then allows it to evaporate. This system, illustrated in Figure 6, allows immediate removal of sweat from the skin with evaporation unhindered by layers of fabric. Dryline® by Milliken is a two-layer fabric with a polyester inner layer and a polyamide outer layer and is most commonly used to line waterproof or breathable outerwear.

Table 2

Fabric Parameters				**Thermal Insulation (m^2 °C W^{-1})**	**Resistance to Evaporative Heat Loss (m^2 mm Hg W^{-1})**	**Moisture Vapour Permeability Index (%)**
Construction (Warp Knitted Fabrics)	**Fibre Content**	**Thickness (mm)**	**Area Density (gm^{-2})**			
3D Eyelet	72dtex / 72fils Textured Polyester	0.21	120	0.08	0.16	74
Pique	72dtex / 72fils Textured Polyester	0.32	140	0.13	0.23	34
Mock Rib	72dtex / 72fils Textured Polyester	0.51	140	0.11	0.24	57
Micromesh	72dtex / 72fils Textured Polyester	0.29	130	0.10	0.11	54

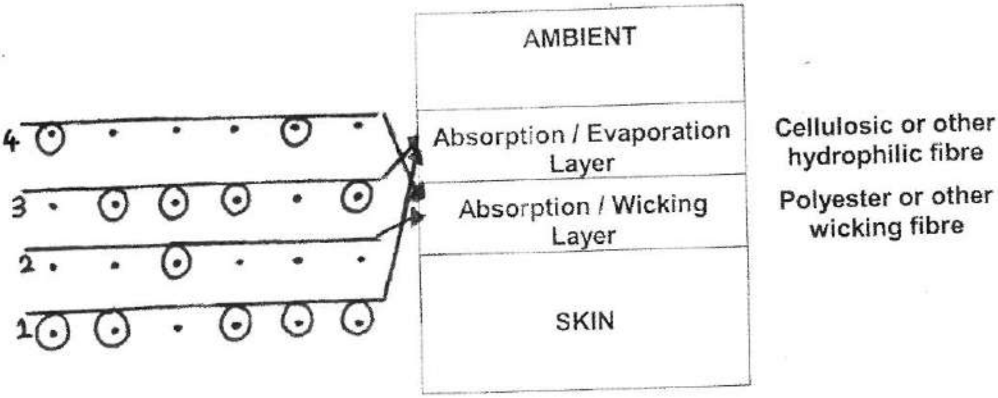


Figure 6: Two-layer Weft Knitted Structure

Alternative two-layer fabrics are available that use the same fibre type throughout. For example, Tactel® Aquator® by DuPont in which the inner layer is made from Tactel® fibres and the outer layer is made from fine filament Tactel®. The difference in properties between the two layers act to draw moisture away from the skin. DriClime® by Marmot is a bi-component tricot knit made from two 100% polyester yarns. The inner layer has a brushed surface and is made from large diameter yarns. The outer layer is made from thin staple-fibre yarns with increased capillary action which act to pull moisture through the fabric.

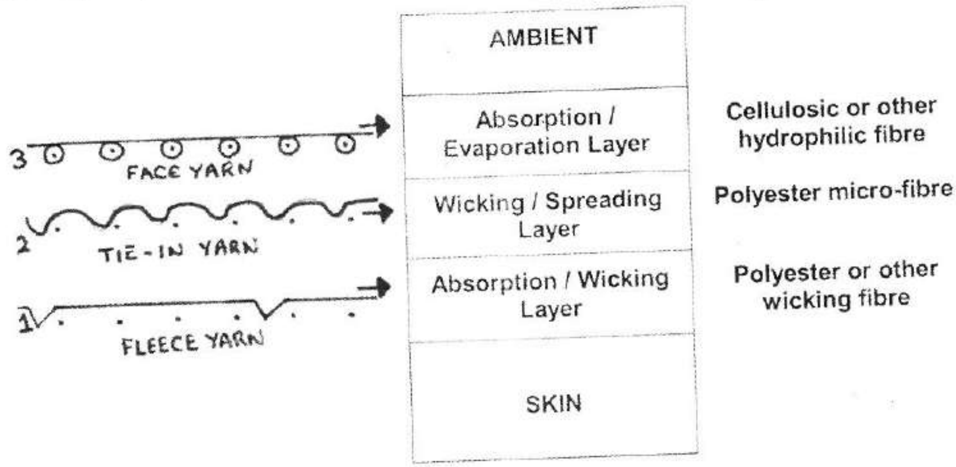


Figure 7: Three-layer Weft Knitted Structure

A more complex 3 x 1 weft knitted fleece fabric (Figure 7) comprising a staple-fibre polypropylene fleece yarn, a CoolMax polyester tie-in yarn and a cotton ground or face yarn has been designed at Bolton Institute as an ideal multi-layered fabric for use in activewear and sportswear. Two further examples of two-layer structures are illustrated in Figure 8. In these specific yarn types are used on different feeds around the circular interlock machine.

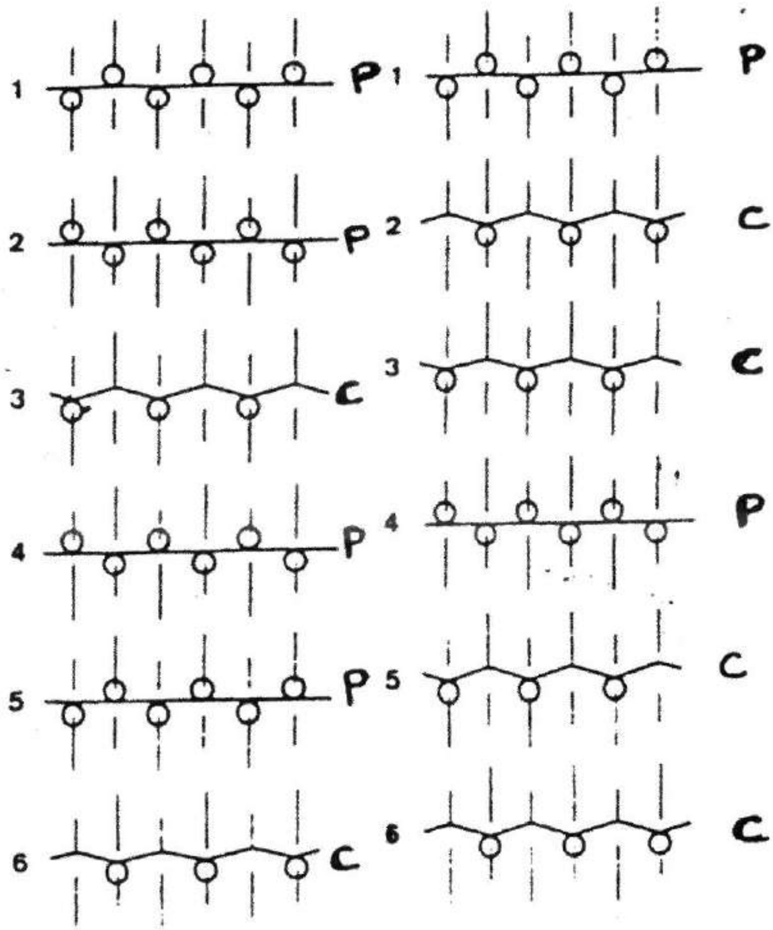


Figure 8: Potential Two-layer Weft Knitted Structures for Sportswear (Left Structure = Single Pique, Right Structure = Pin Tuck; C = Cotton yarn, P = Polyester yarn)

One significant example of designing sportswear garments has been the design and development of Sportwool™ materials. These have been successfully used in many sports including as football shirts for Manchester United Football Club. The fabric is designed as a two-layered material with woollen yarns made from extremely fine Merino wool fibres (<20 μm), which are chemically modified and used in the fabric layer next to the skin. The outer layer is made from 100% filament polyester yarn. The wool fibre is comfortable and has a good water vapour permeability which transfers heat and moisture from the skin to the outer surface, where heat and moisture are allowed to evaporate aided by high wind speeds and body movement.

Some relevant comfort properties of a standard Sportwool™ material and the two layer fabric illustrated in Figure 6, made from 100% filament polyester and cotton yarns are given in Table 3. It must be pointed out that in the latter fabric the 100% polyester layer is worn next to the skin.

Table 3: Properties of Different Two-layer Fabrics

	Sportwool™	Two-layer Structure
Area Density ($g\ m^{-2}$)	161.23	161.18
Thickness (mm)	0.64	0.75
Bulk Density ($g\ cm^{-3}$)	0.252	0.215
Dry Thermal Resistance ($W^{-1}\ K\ m^2$) x 10^{-3}	24	24.15
Wet Thermal Resistance ($W^{-1}\ K\ m^2$) x 10^{-3}	10	13.75
Dry Thermal Absorptivity ($W\ m^{-2}\ s^{1/2}\ K^{-1}$)	83	74.3
Wet Thermal Absorptivity ($W\ m^{-2}\ s^{1/2}\ K^{-1}$)	328	246
Water Vapour Permeability (%)	36.5	39.75
Resistance to Evaporative Heat Loss ($m^2\ Pa\ W^{-1}$)	0.0155	0.0258
Absorption ($g\ g^{-1}$)	3.59	4.47
Wicking / Course Direction (g cm)	3.64	4.74
Wicking / Wales Direction (g cm)	2.61	6.04
Wicking / Area (g cm)	3.08	5.35

It will be observed in Table 3 that although different fibre types and structures are used in the two popular sportswear fabrics, their comfort properties are somewhat similar. Both fabrics have similar thermal properties, but the water vapour permeability of the polyester and cotton combination fabric is somewhat superior to the Sportwool™. The Sportwool™, however, exhibited a lower resistance to evaporative heat loss and also possessed somewhat lower absorption and wicking characteristics than the two-layer sportswear fabric developed at Bolton Institute.

Layered Clothing

An efficient clothing system can be created through the use of layers of clothing. For optimum comfort in sportswear a three layer system can be used. The base layer, often underwear, vests and leggings etc., will provide the primary moisture management mechanism by wicking moisture away from the skin. These garments should fit tightly in order to act efficiently. The middle layer should be lightweight, breathable and provide good thermal insulation. This layer need not be tight fitting as the layer of air beneath this garment can substantially increase thermal insulation. The outer layer should be windproof, breathable and, depending on its application, could also be waterproof.

EFFECT OF FINISHING AND CHEMICALS

The use of appropriate finishing techniques can substantially improve the moisture management properties of certain fabrics. In work carried out at Bolton Institute a warp knitted pique polyester fabric was treated with four commercially available finishes which modified the surface of the fabric and were recommended for increased absorbency and wicking. As can be seen from Table 4: all four treatments improved the absorbency of the polyester fabric with treatment 'C' giving values close to that of the highly absorbent cotton fabric. Treatments 'A', 'C' and 'D' produced very significant improvements in wicking capacity and rate.

The recovery behaviour of the thermal insulation of the 3 x 1 weft knitted fabric, illustrated in Figure 7, was investigated after the fabric had been wetted out with water. It took 20 minutes to recover 75% of the fabric's dry thermal insulation value. The effect of the application of 2% w/w hydrophilic softener designed for use with synthetic fibres (Sandotor HV) to this fabric was also observed. For the finished fabric there was a 75% recovery of the dry thermal insulation in under 4 minutes. The importance of using the right hydrophilic softener with a given fabric was demonstrated when the same three-layered fabric was treated with 2% w/w hydrophilic softener designed for use with cellulosic fibres (Alkosoft). In this instance the finish influenced the rate of wicking with 75% recovery of dry thermal insulation only after 22 minutes.

Table 4: Effect of Finish on Absorption and Wicking Parameters

Fabric Type	Absorption Capacity ($g\ m^{-2}$)	Absorption Rate ($g\ m^{-2}\ s^{-1}$)	Wicking Capacity ($g\ m^{-2}$)	Wicking Rate ($g\ m^{-2}\ s^{-1}$)
Bleached Cotton	221	60	103	0.75
Knitted Pique Polyester (KP)	52	3.2	73	1.12
KP treated with finish 'A'	152	46	227	7.52
KP treated with finish 'B'	88.4	15.8	64	0.9
KP treated with finish 'C'	219	66	238	5.12
KP treated with finish 'D'	94	59	214	4.86

Table 5: Effect of 'Comfort Finish' on Polyester Football Shirts

	As Received	Comfort Finished
Thermal Insulation of Dry Fabric ($m^2\ ^\circ C\ W^{-1}$)	0.0090	0.0110
Thermal Insulation of Damp Fabric ($m^2\ ^\circ C\ W^{-1}$)	0.0026	0.0020
Resistance to Evaporative Heat Loss of Dry Fabric (m^2 mm Hg W^{-1})	0.20	0.20
Resistance to Evaporative Heat Loss of Damp Fabric (m^2 mm Hg W^{-1})	0.21	0.18
Air Permeability ($cm^3\ cm^{-2}\ s^{-1}$)	79	53
Water Vapour Permeability ($g\ m^{-2}\ hr^{-1}$)	1426	1223
Absorption Capacity ($g\ m^{-2}$)	52	219
Absorption Rate ($g\ m^{-2}\ s^{-1}$)	3.2	66
Wicking Capacity ($g\ m^{-2}$)	73	238
Wicking Rate ($g\ m^{-2}\ s^{-1}$)	1.1	501
Rate of Drying ($g\ m^{-2}\ s^{-1}$)	0.14	0.11

A further example of the benefit of appropriate finishing can be seen in a comparison of the properties of a conventionally finished 100% filament polyester football shirt with the same shirt that had been finished with a hydrophilic softener designed for use with synthetic fibres (Table 5). The application of the finish significantly improved the water absorption and wicking properties of the shirt without impairing the other properties.

Conventional waterproofing materials usually consist of finishing a woven base fabric by coating it in vinyl or rubber. These materials, however, do not allow insensible perspiration to pass thereby causing perspiration to build up in the fabric. Textile materials have been developed which are waterproof, water vapour permeable and breathable. An example is Goretex® by Goretex Industries which is a micrporous membrane with pore size of approximately 0.25 µm.

Using a stain release finish such as Teflon® by DuPont can improve the stain resistant properties of synthetic fibres without compromising their thermophysiological properties.

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Advanced Teflon® - Innovation Benchmark

— AVINASH ORPE

It is long being known that Teflon® offers excellent protection against stains of various kinds, with its dual systems of stain repellent or stain release properties. There was however always a problem with regards to many stubborn ground in stains, which are very difficult to repel. With these stains it was difficult to offer complete protection. The ring around the shirt collar is one such example. Here due to the constant brushing of the fabric against the neck, however protected the collar is, a ring of dirt is always formed around the collar. This is also extremely difficult to wash of because of the ground in stain. With the new Advanced Teflon® concept, which combines the stain repellent and stain release properties together in one fabric, the staining of the collar is reduced considerably and whatever staining has taken place is washed off during the washing due to the stain release properties of the system.

The first hydrophobic agents in the market were based on paraffin emulsions and fat modified cellulose cross-linkers. These products imparted good water repellency and high water pressure resistance. However, the fastness of these products, especially to dry cleaning, was very limited. Later, silicones came into picture. However, the oil repellency of silicone-based products was extremely poor. Dr. Roy Plunkett of DuPont (now renamed as Invista) discovered PTFE on 6th April 1938. This was the start of the development of fluorochemical applications. Since then the fluorochemicals have come a long way and have now become more or less a part of the standard range of effects on textiles. Besides the high effect level, the durability in use is one of their remarkable characteristics.

The water repellent effects are mainly based on the reduction of the surface tension of the finished fabric. In the majority of cases, this surface energy is less than that of the wetting liquid - in this case water - which results in a chemical barrier against penetration of the liquid.

Of all textile chemicals, only fluorochemicals show this unique property to reduce the surface energy to such an extent that repellency, against both, aqueous and oily based substances (polar and non-polar liquids), is granted.

THE TEFLON® HANGTAG

Since 1990 Ciba and Invista have been cooperating in the field of fluorochemicals. The synergy, Invista as the biggest manufacturer of fluorochemicals and Ciba as one of the market leader in the field of chemicals for the textile industry, effectively covers the complete market requirements.

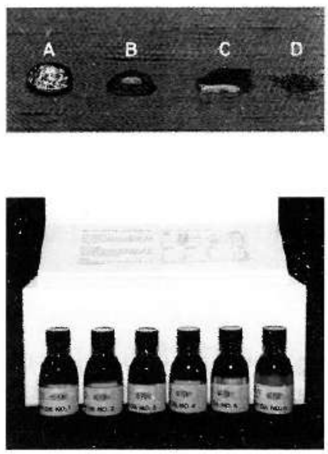
The use of fluorochemical with the brand name "Ciba® OLEOPHOBOL®" allows a high level of effects to be achieved on the textiles. This is visible to the consumer by way of a TEFLON® Hangtag. A prerequisite for marking a fabric with the TEFLON® Hangtag is to meet the specifications related to the corresponding end use. The fabric is subjected to stringent quality control. The arrangement between Invista and Ciba is such that Invista will do promotion / marketing of the TEFLON® brand, whereas Ciba will provide Technical Service / marketing efforts for the chemicals as well as testing for specifications. This means that there is an entire organization of Invista involved in TEFLON® brand marketing, and Ciba, with its expertise in textile processing, can take care of all kinds of problems that the customers may face during application of the fluorochemicals on the shopfloor.

The performance for water repellency is tested using Water Spray test (AATCC 22 -1989) for outerwear fabrics and DuPont water drop test for all other fabrics, where as the oil repellency is tested using six different special formulation oils numbered 1 to 6. (AATCC 118-1989). These are internationally recognized standard test methods.

EVOLUTION OF EFFECTS:

The effect levels required have continuously evolved over the last 40 years. Initially the requirements were restricted only to TEFLON® and TEFLON® HT brands. For these standards to be met the fabric is tested for oil and water repellancy as such after finishing (initial) as well as after 5 launderings at 60C for TEFLON® and after 20 launderings for TEFLON® HT finish. For these effects the fabric needs to be ironed before testing. These simple effects were in vogue for many years without any new requirements coming in. Recently however, with the advent of easy to iron and wrinkle free fabrics, ironing the fabric is

Spray Test



Drop Test

becoming out of fashion. Ciba and Invista have stayed in touch with the changing demand and consumer requirements. This has resulted in development of newer finishes like TEFLON® LAD and TEFLON® LTD. In these cases the fabric is tested after laundering either after air-drying (LAD) or after tumble-drying (LTD). No ironing is carried out. This has made the conditions much more real life from the consumer point of view, but more challenging from the suppliers point of view.

Apart from these there are also other special requirements where laundering is not so important, but special testing is needed. Ciba Invista, have been understanding, these demands and have developed special testing for these requirements. For upholstery fabrics, which are subjected to abrasion (e.g. seat covers), fastness to abrasion and performance after a certain level of abrasion is also tested.

Then there are also other requirements, like for children-wear the preferred effect is to have a stain release finish rather than a stain repellent finish. In this case rather than repelling the stains, the stains are absorbed and then released during the home laundering cycle.

Despite all these effect innovations, so far consumers only had to select from either stain repellant or stain release finish at one time depending on the end requirements. This meant many times they had to compromise on certain requirements. With precisely these effect lacunas in mind Invista / Ciba has now launched the latest concept of Advanced Teflon® fabric protector.

This is the newest and most innovative chemistry, which offers a dual action repel and release system. This integrated Teflon® fabric protector is even more effective on hot and difficult liquids as well as ground-in and oil based stains. With this Advanced Teflon® concept consumers now get twice the stain protection in one easy-to-care-for fabric.

It is the most durable stain and soil protection product available for apparel and also washable furnishings. It takes away the worry of permanent, costly damage and keeps fabrics looking new longer. Also in line with the Teflon® concept, Advanced Teflon® effect also does not change the weight, look, feel, colour and breathability of the fabric.

TOTAL STAIN PROTECTION SYSTEM:

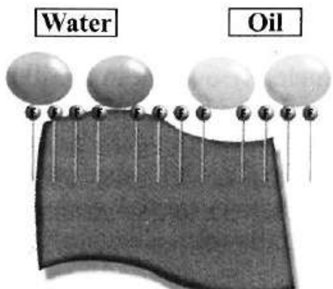
First line of defence

Stain repellency is the first critical line of defence. Advanced Teflon® utilizes a fluorochemical finish that forms a molecular barrier at the nanoscale around individual fibres. This intelligent technology repels oils and water based liquids.

The result

Liquid spills bead up and off and any residue can be easily wiped away or blotted with a clean cloth. Dry soil can be brushed off easily

REPELLENCY BENEFITS



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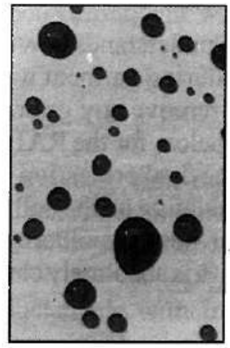

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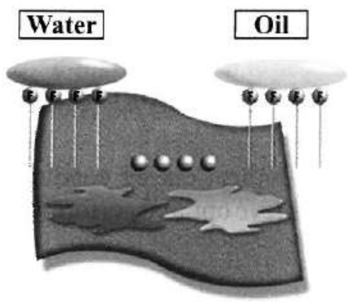
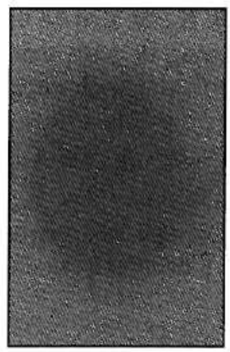
Second line of defence

The same fluorochemical finish that repels liquids also has a component that releases ground-in stains, preventing them from becoming permanent.

How it works

A water-loving component draws detergent and water into the fibre during laundering Stains are released from the fabric, leaving it looking like new





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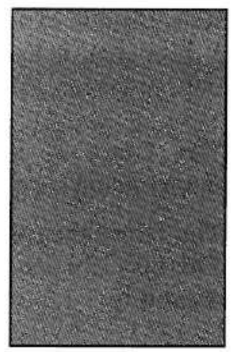

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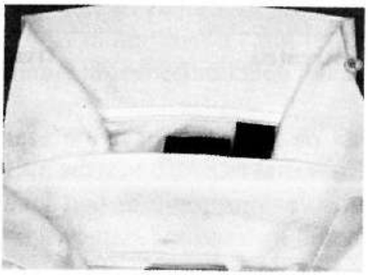
After Washing

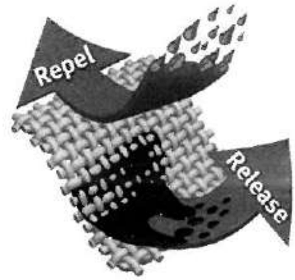
Superior performance

Advanced Teflon® retains its durability even after dozens of launderings and cleanings. In fact it is tested and guaranteed for the specified performance up to 20 launderings. With the advantage of both repel and release properties in the same fabric, the effect is perfect for khakis, shirts, knit tops, linens, children apparels etc. The durability and performance can be tailor-made based on the end use application and life span needs.

Advanced Teflon® fabric protector is a Smart Material

Which understands how to keep clothes looking cleaner, longer. It repels oil and/or water based stains during garment wear, and works with (not against) detergents in the laundry process to easily remove any ground-in or residual stain. This is also clearly evident in the illustration given below for the RATC (Ring Around The Collar) stains, which are most notorious to wash off. The dual protection system offered by Advanced Teflon® finish prevents the stains from accumulating on the collar and whatever small staining does take place is washed off during the normal home laundering. The upper collar in the picture below, treated with Advanced Teflon® is absolutely clean, while the untreated collar below has developed severe RATC.





Applying Teflon®

Padding is the most common and efficient method for applying Teflon® because it requires no additional capital expenditure. It can also be applied in a variety of other ways: by vacuum, foam, kiss coat, exhaust, coating or yarn treatments. For enzyme-washed apparel such as stonewashed jeans, garment finishing is also an option. Here's how the pad process works:

- The fabric is immersed in a water bath containing Ciba® OLEOPHOBOL® fluorochemical products.
- The fabric then travels through an oven to dry and cure typical curing conditions are 170180°C for one minute. Curing is a crucial final step to achieve optimal performance and durability.

Superior Performance & Compatibility

Because it's built-in, Advanced Teflon® retains its durability after dozens of launderings and cleanings. Unlike some other stain protectors, Advanced Teflon® does not require ironing to regenerate its stain protection. In addition, Teflon® brand products are compatible with other finishing agents such as wrinkle-resistant additives and selected softeners.

Product Stewardship

Invista as the technology supplier is committed to the safety of our products with over 35 years of testing. Invista meets and exceeds all global government safety standards with our ongoing product stewardship efforts and by working collaboratively with agencies around the world.

BRAND EQUITY & MARKETING

Through unparalleled marketing support, including a consumer campaign with marketing opportunities available to our partners, we continue to build strong consumer preference for Teflon® fabric protector. Because of these aggressive marketing efforts, Teflon® fabric protector enjoys overwhelmingly high consumer awareness:

80 percent of consumers surveyed say they'd repurchase a product made with Invista™ Teflon®.

97 percent of consumers are aware of Invista™ Teflon®, identifying it with innovation that makes their lives easier.

We are sure, with the kind of value addition possibilities that exist with the TEFLON® products and especially with the ADVANCED TEFLON® finish that the key to this value added market will remain firmly in your hands.

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Bioactive Textiles From Natural Sources : *Mallotus Philippinensis*

DEEPTI GUPTA & ANKUR LAHA

Odour production in textiles is a major nuisance. As the consumers become more and more health and hygiene conscious, market is being flooded with antibacterial products which inhibit odour generating microbes. Interest is growing in products obtained from natural - particularly plant-sources which are non allergenic and non polluting. This study was undertaken to screen some commercial natural dyes for their antibacterial properties. Detail studies were carried out with Mallotus philippinensis especially with respect to the body odour causing bacteria namely Staphylococcus aureus, Proteus vulgaris and Bacillus subtilis. Results show that the dye is highly effective against the tested microbes.

Today's customers are becoming more and more aware of problems caused by microbes. One major problem is that of odor generation. Human sweat is not a problem if it is allowed to evaporate to air, but since we wear clothes that restrict such natural evaporation, bacteria present on the skin and on clothes decompose perspiration into various chemicals, some of which cause offensive odours. Bacteria can grow particularly rapidly on natural fibres because of the warm and moist environment that they provide. Some of the common microbes and their effect on human body is shown in Table 1.

Body odour is the smell caused by bacteria feeding on the sweat which comes from the apocrine glands in the armpits and groin area. Sweat produced from the rest of the body is made by endocrine glands. It is saltier, and does not encourage the growth of bacteria and therefore doesn't smell. Sweaty feet may smell unpleasant because we wear shoes and socks which provide the warm, enclosed environment which is ideal for bacteria and fungi to grow. For example, the characteristic body odour is caused by 3methyl hexanoic acid, produced by Staphylococcus aureus bacteria and on metabolism of urea to ammonia by Proteus vulgaris. Logically, therefore, the problem of odour can be tackled either by trapping the odor causing molecules or by preventing the formation of odour causing molecules by inhibiting the growth of bacteria. Deodorant and antimicrobial finishes termed as hygienic finishes are thus rapidly becoming a standard finish particularly in some textile categories such as legwear, footwear, lingerie, babywear, sportswear, health care products, and, more recently, home furnishings. These finishes act by either or both of the mechanisms mentioned above.

Application of natural antimicrobial agents on textiles dates back to antiquity, when the ancient Egyptians used spices and herbs to preserve mummy wraps. It is predicted that in the future too, natural products will continue to play a major role as active substances against microbial growth. In recent years, a number of studies have been undertaken to study the antimicrobial properties of natural materials[1-5]. Although these natural materials might be limited in their practical use, it seems that they have several advantages such as non-toxicity, specific biological activity and environment friendliness which work in their favour.

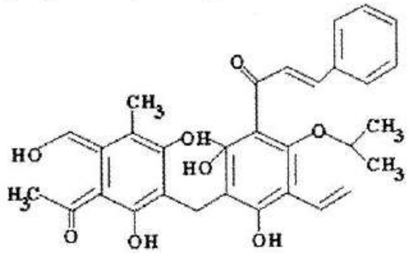
Table 1. Some common microbes and their effect on human body

Species		Name of microbes	Diseases
Bacteria	Gram positive	*Staphylococcus epidermidis*	Body odor
		Corynebacterium diphtheroides	
		Micrococcus luteus	
		Proteus vulgaris	
		Brevibacterium ammoniagenes	Diaper rash
		Erysipelothrix rhusiopathiae	Skin rash
	Gram negative	*Escherichia coli*	Infections of UTI
		Klebsiella pneumoniae	Pneumonia
		Salmonella typhi	Typhoid
		Shigella dysenteriae	Dysentery
		Vibrio cholerae	Cholera
Fungi		*Aspergillus flavipes*	Rot causing
		Aspergillus niger	
		Candida albicans	Diaper rash
		Trichophyton interdigitale	Foot infection
		Trichophyton rubrum	Infection in nails and skin
Viruses		*Poliomyelitis*	Poliomyelitis
		Vaccinna	Localized diseases
Protozoa		*Trichomonas vaginalis*	Trichomoniasis vaginitis

Studies are being conducted by the investigators on the antimicrobial properties of natural products and natural dyes in particular so that without any special additive or treatment, textiles can be rendered antimicrobial during dyeing itself. 11 dyes have been tested for this purpose and detail studies are being carried out on various natural and synthetic fibres [6-9].

The current study was undertaken to study the anti microbial activity of cotton textiles dyed with *Mallotus philippinensis*. The activity has been studied especially with respect to the body odour causing bacteria namely *Staphylococcus aureus, Proteus vulgaris* and *Bacillus subtilis*.

The granular red powder covering the fruits of the plant *M.philippinensis* is extracted and used in eye-diseases. Also known as *Kamala* and *Kapila* it is a popular folk remedy for tape-worm. Taken internally, *Kamala* reportedly removes leprous eruptions. The powder has been used to produce an orange-brown dye for coloring silk. The special properties of *M. philippinensis* are attributed to the presence of a red dye called rottlerin. The plant has been widely researched in recent times for its medicinal properties.[10-13].



Rottlerin

Materials and Methods
Dyes and chemicals

M.philippinensis dye was procured from Alps Industries Ltd, Sahibabad. $CuSO_4.5H_2O$, $Fe_2SO_4.7H_2O$ and alum of LR grade were used as mordants. Antimicrobial efficiency of the extract was compared against the activity of commercial antimicrobial agent - Fabshield AEM 5700, marketed by Rossari Industries Ltd.

Bacteria: Bacterial strains were obtained from MTCC (Microbial type culture collection),Chandigarh. *Staphylococcus aureus, Bacillus subtilis and Proteus vulgaris* were used for the study.

All materials were sterilized prior to use. Anti microbial activity was determined by the Disc diffusion method by measuring the zone of inhibition around the filter paper disc over the solid culture media in petri dishes. The lowest concentration at which the dye showed a zone of 2mm was established as the MIC of the dye for the test microbe.

Determination of antimicrobial activity of dyes on dyed fabrics

Colony counting method: It is a quantitative test method, where the bacteria are inoculated on the test fabric and incubated. The microbial inhibition was determined by colony counting before and after incubation by using equation I.

$$R = \frac{(C - A) \times 100}{C} \qquad (I)$$

Where:

R= % Reduction

C=the number of bacteria recovered from the inoculated untreated control specimen

A= the number of bacteria recovered from the inoculated treated test specimen

Dyeing of cotton with Mallotus philippinensis

Scoured cotton fabric was used for dyeing with *M. philippinensis*. Natural colours are generally applied in combination with metal salts or mordants for better fixation and deeper colours. So the effect of addition of aluminium potassium sulphate (alum) on the antimicrobial activity was also tested. Dyeing of cotton fabric was carried out with following particulars. Dyed sample without mordant were also prepared. The dyed fabric samples were washed with cold water, soaped with non ionic detergent and dried. The K/S value of each dyed sample was measured by Jaypac colour matching software.

Dye % --------------------- 1, 6, 12, and 15.
Alum % --- 0.5 and 5 (80C for 30 minutes).
MLR ----------------------- 1:30
Temperature ---------------- 80°C

Results and Discussion

Several concentrations of the *M. philippinensis* extract were tested for antimicrobial effect by the disc diffusion method. Results are reported in Table 2. The dye shows good activity against all tested microbes. The MIC against *P.vulgaris* is higher as compared to the other two microbes. While the activity levels off against *S.aureus* and *P.vulgaris* beyond the MIC, it continues to increase exponentially against *B.subtilis*, as concentration is increased.

Table 2 Effect of dye concentration on antimicrobial activity

Microbes	Conc. of dye (%)	Mean diameter of zone of inhibition (mm)
S.aureus	0.3	1
	0.5	1.5
	1*	2
	3	2
	5	2.5
B.subtilis	0.3	1.5
	0.5*	2
	1	2.5
	3	3
	5	5
P.vulgaris	0.5*	2
	1	2.5
	2	2.5
	4	2.5
	5	3

** MIC of M.philippinensis against selected microbes*

Determination of activity of *M.philippinensis* on cotton textile

Cotton dyed with *M.philippinensis* was tested for activity against *S.aureus* and *B.subtilis*. Effect of addition of alum as a pre treatment was also studied. Estimation was done by calculating the reduction in colony forming units (CFU). Results are reported in Table 3.

Table 3. Evaluation of microbial activity of cotton treated *with M.philippinensis*

	Bacteria used for the test			
	B.subtilis		*S.aureus*	
Conc. of dye/mordant	Growth below fabric	Zone of inhibition (mm)	Growth below fabric	Zone of inhibition (mm)
Control	+	0	+	0
Fabshield	-	-	-	-
12 %	-	2	-	0
15 %	-	2	-	0.5
12% + 0.5% Alum	-	0	-	0
15% + 0.5% Alum	-	0	-	0
12% + 5% Alum	-	0	-	0
15% + 5% Alum	-	0	-	0

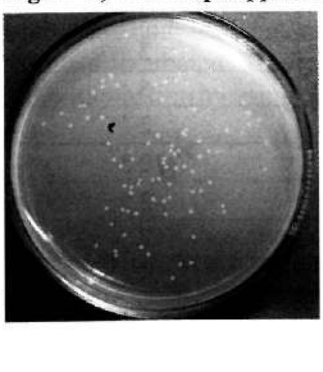
+ = growth is seen, - = no growth

It is obvious that the dyed fabric has some inhibitory effect on the selected microbes as no growth is seen under the fabric in all treated samples. Around the samples.dyed with 12% and 15% dye, a 2 mm zone of inhibition was observed. However, no zone could be seen after the addition of alum. There could be two reasons for this behaviour-1) that the activity of dye is reduced or lost after it complexes with the dye and 2) the zone of inhibition is shown only by those anti microbial agents which have a tendency to leech out into the medium and kill the microbes in the vicinity. Non leaching type agents which have durable activity do not show any zone.

To confirm this, another set of experiments was conducted to estimate the % reduction in microbial colonies by the colony counting method. A representative plate used for colony counting is shown in Fig.1. Results of the colony counting tests are shown in Fig.2 and 3 for *B.subtilis* and *P.vulgaris* respectively.

Fig. 1 a) 12% *M.plilippinensis* dyed sample **b) control against *B.subtilis***

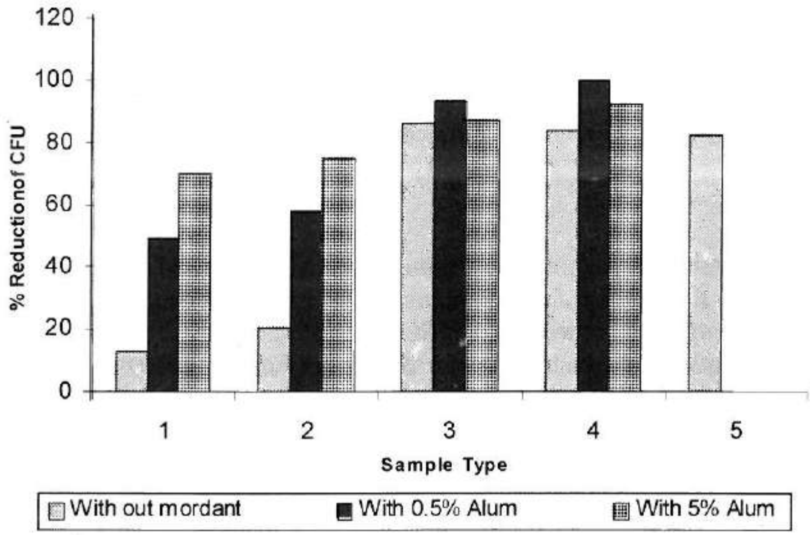
(a)



(b)

It can be seen from Fig.2 that even cotton dyed with 1% *M.phillipinensis* shows antimicrobial activity against *B.subtilis* but it is very low. The activity increases with increasing concentration and at 15% there is 89.7% reduction in microbial colonies. Addition of alum at lower concentrations of dye leads to significant enhancement in activity. Best results are obtained at 15% dye with 0.5% alum where 99% inhibition is there compared to 98% inhibition shown by commercial agent Fabshield. Activity is reduced marginally at higher concentration (5%) of alum coupled with higher concentration of dye.

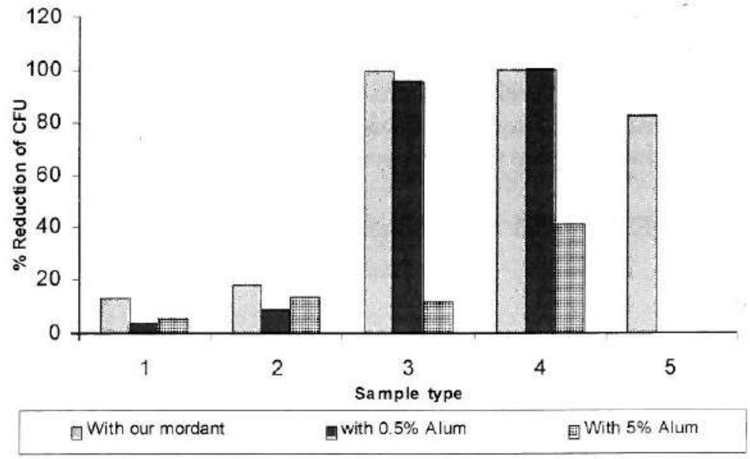
Fig 2 Effect of dye and mordant concentration on *B.subtilis*



The dye is more effective against *S.aureus* as compared to the previous microbe, showing >99% inhibition at 12% concentration and almost 100% inhibition at 15% as compared at 98% of Fabshield. Only alum treated sample shows 82.4% inhibition of *S. aureus*. But samples treated with a combination of dye and alum show reduced activity. This may happen if some of the functional moieties present in the dye which are responsible for the antimicrobial effect are capped by metal-dye chelate formation.

From this preliminary study it can be concluded that the selected dye can be used as an effective anti odour or antimicrobial agent on textiles. 12 to 15% concentration on cotton gives complete inhibition of odor causing microbes. Amount of alum to be used can be optimized to develop a finish which is more durable and effective. It is a dual purpose, eco friendly treatment that imparts colour as well as functionality to textiles.

Fig 3. Effect of dye and mordant concentration on anti microbial activity of cotton fabric dyed with *M.philippinensis* on *P.vulgaris*



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Digital Printing : A Tool For Demand Activated Textile Printing

— RB CHAVAN

Wide spread acceptance of demand activated manufacturing and just in time marketing concepts have put tremendous pressure on textile printers. Presently available rotary screen printing equipments are often inflexible in terms of quick customer response and short runs and thus not suitable for mass customization. In the present article an attempt has been made to critically review the technology of digital printing. The technology has achieved considerable success till the pre-production stage and continuous efforts are being made to perfect the technology for production printing. It is envisaged that once the digital printing technology is perfected, a customer instead of purchasing the printed fabric available in stores may be able to scan the design on computer, select the design and colour combination or create a new design and feed the information to the digital printer and get the printed length of the fabric with a design of her/his choice.

The art and science of decorating fabric with colourful designs is known as textile printing. Conventional textile printing techniques such as block printing, flat and rotary screen printing are known as analog printing where a master image present on block or screen is reproduced onto textile in the form of print. In Digital printing the design is in the form of electronic file in a computer. The computer is linked to a suitable machine e.g. inkjet printing with the help of which the design is printed onto paper or fabric in the form of analog image with the help of coloured microscopic dots. This means that the master design in the form of electronic data is converted into analog image without the help of individual screen/block/roller for each colour.

TEXTILE PRINTING TECHNOLOGY TRENDS

Rotary screen and flat bed screen printing are the major textile printing techniques prevalent presently. The textile printing production technology trends are shown in figure 1.

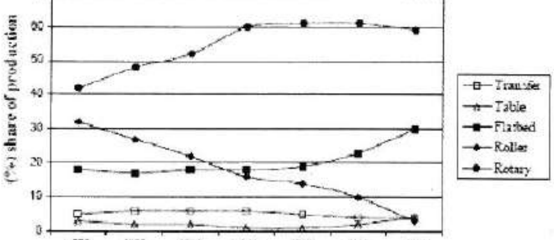

Figure 1 Production technology trends

Rotary screen-printing is the most popular production technology and is likely to remain so for several years to come. Presently the share of rotary screen printing is 60% Due to decreased production in the West but strong growth in the Far East, where flatbed production is predominantly used, has meant that the flatbed share has increased. This reflects the cheaper labour costs that render this relatively labour intensive method economical to use. A further reason for the increase in flatbed printing is the reduction in average production run length.

TRENDS IN GLOBAL PRINTING MARKET

Textile printing is cyclical business and fashion dependent. The fashion seasons are becoming shorter resulting in 5-6 fashion forecasts in a year. Customers are demanding great variety of colours and unique designs. Consumers want clothes to express their individuality in homes and the clothes they wear. Due to these reasons there has to be quick sampling and quick order turnaround. The chances of repeat orders are becoming rare. In addition to this average run lengths are rapidly dropping. Thus the world of textile printing is rapidly changing. Globalization, quick response and ecology aiming at waste minimization and reduced environment pollution impose substantial demands on the different components of the printing process. In short: these demands have common denominators: flexibility and versatility. In order to meet such market demands there must be a technology which will facilitate Mass Customization. It is a new concept of production which specializes in short runs as little as one unit in which the customer dictates exactly his/her requirements. It aims of producing unlimited designs of customer's choice. If one does not mass customize one would lose business in today's market.

Digital printing technology supports the present industrial trends: short runs at economical cost, quick delivery, exclusive unique designs and personalized textiles. Digital printing can also contribute to the 'green image' of textiles; the ecological impact is clearly lower compared to conventional printing. Digital printing means flexibility and a quicker response to the market demands. Digital printing is already applied for sampling, strike-offs, short runs and mass customized apparel. It allows the user to bypass the extremely time consuming and expensive screen making process, providing the opportunity for quick changes to colour or design elements prior to printing.

The conventional printing requires 6-7 weeks whereas the digital printing requires about 2.5 weeks delivering the final printed products (Table 1). In addition to this the change over from one colour scheme to other and from one design to another is also much simpler and less time consuming in case of digital printing.

Table 1. Time to introduce a new product

	Conventional	Digital
Color Separation, design editing	2 weeks	2 weeks
Digital Fabric Samples	-	2-4 days
Engrave Screens	4 days	-
Strike-offs	2 weeks	-
Sample Yardage	4 weeks	-
TOTAL	6-7 weeks	2.5 weeks

DIGITAL PRINTING TECHNOLOGIES

There are various technologies available for digital printing. Among these the most popular is ink jet printing technology. The principle of operation involves directing minute droplets of ink, from a nozzle, onto the printing substrate. Although there are different ways of producing the droplets, a common feature is the computer control of droplet position on the substrate by their response to high frequency digital electronic signals. The droplet formation involves the application of a controlled pressure on the liquid ink in its reservoir as it streams into the printing nozzles the ink stream is broken into droplets.

There are two main technologies applied to ink jet printers, continuous ink jet and drop on demand. Their application can be further subdivided as indicated in Figure 2

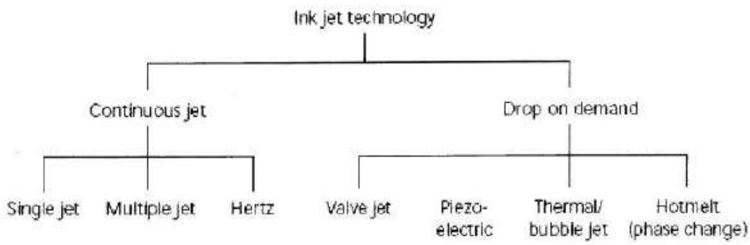

Figure 2 Ink jet technologies

CONTINUOUS JET

In this technology, a continuous stream of ink is produced by forcing it through a narrow nozzle at a pressure of about $3x10^5$ Pa. The resulting high velocity breaks the ink stream into droplets. Directional control over the droplets is obtained by inducing an electrostatic charge on them as they leave the nozzle. The charged droplets then pass through a set of like-charged plates which repel and deflect the droplets to the required position on the substrate. Figure 3 shows the principle of operation of a single jet system.

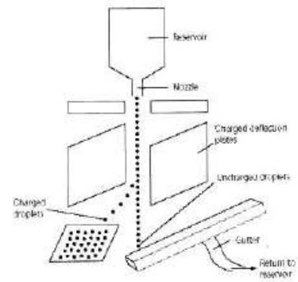

Figure 3 Continuous inkjet

The continuous inkjet is the oldest technology. Currently the main direction of research has moved to 'Drop on demand' digital printing technologies

DROP-ON-DEMAND TECHNOLOGY

Two main types of print head technologies are available in this category

1. Thermal (or bubble-jet)
2. Piezo drop on demand.

In these technologies the pressure applied to the ink reservoir is not continuous, but is only intermittently applied when a droplet is needed.

Thermal ink jet or bubble jet technology

The bubble jet printer (Canon) uses a small heating element to create pressure droplets on demand within the ink reservoir. The small quantity of ink present in each nozzle is heated by a resistive heating element actuated by the digital data stream. The ink boils creating a bubble which forces an equivalent volume of ink droplet through the nozzle and onto the substrate (Figure 4).

Thermal ink jets offer low-cost print heads but suffer from reliability and slow speed. Thermal

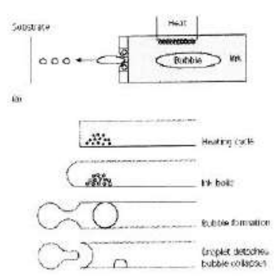

Figure 4 Thermal inkjet printer: (a) Bubble jet chamber; (b) bubble formation

printers are well suited for low-volume printing. The system restricts the use of binder containing pigment inks. The major problem with the thermal ink jet is the high nozzle and resistor failure rate resulting from rapid thermal cycling. The high temperatures cause often decomposition of ink components, which leads to nozzle clogging. Therefore, only thermally stable inks can be used. Poor quality production results are possible. Finally, compared to piezo-systems the droplet size is larger resulting in a lower resolution. Main players are Canon, Encad, Color Wings, HP, and Direct Imaging Systems

Piezo drop on demand technology

This is one of the simplest ways of generating drops on demand. It makes use of the piezoelectric effect in which small electronic impulses delivered to suitable crystalline materials (transducer) causes them to expand. This transducer, incorporated in the ink reservoir, enables pressure pulses to be created in the ink. Droplets are generated intermittently according to the electronic signals received. (Figure 5)

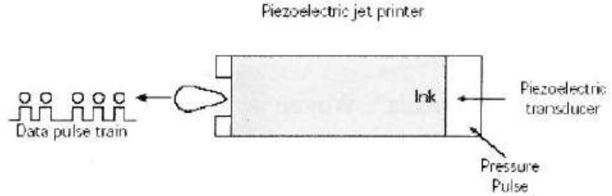

Figure 5 Piezo Drop on demand technology

These printers have the advantage of much greater print head life than the thermal-based systems (100 times). Piezo inkjet printers are now in use in a number of printers for textile substrates. A number of companies (e.g. Konica, Mimaki, Epson) are producing and developing wide format piezo printers for printing wide width fabrics.

Advantages inherently linked to piezo-systems are:

- Ink formulation: as the inks are not heated, the formulation can be less critical and hence the inks less expensive
- Well suited for high-volume printing (industrial)
- Reliability is built-in through design
- Uses a wide range of ink formulations (solvent, water, UV curble)
- Produces high resolution by using small drop size
- Capable of using binder containing pigment inks

ESSENTIAL ELEMENTS OF INKJET PRINTING

The essential elements of a textile inkjet system are:

Inkjet printer

Inkjet printer with one or more inkjet print heads, generates the streams of microscopic ink droplets and direct them to the substrate.

Computer

Computer system for data processing

Software

Including printer drivers, raster image processing (RIP) and colour management systems to convert computer-based designs into the electronic signals which control the scanning inkjet head and machine. These systems can also ensure faithful and reproducible results with different batches of fabric, and provide a total interface with the other components of a digital design, sampling and production environment.

Textile substrates

Often in the digital world called "media". Woven or knitted fabrics are suitable for inkjet printing using appropriate inkjet inks.

Fabric pretreatment

Unstable fabrics such as knits and lighter weight woven fabrics frequently need to be supported by a stiffening binder, or temporary lamination to a support paper.

Fabrics are pre-treatment with various surface active agents, gums and fine particulate coatings in order to maximize the absorbency and reactivity of the textile substrate towards the inks, while minimizing their spreading to prevent loss of definition and colour intensity. Many patented and proprietary formulations exist, ranging from simple formulations of soda ash, alginate and urea to more sophisticated combinations of cationic agents, softeners, polymers and inorganic particulates such as fumed silica. Many of these have been aimed at fashion fabrics such as cotton, silk, nylon and wool. 3P InkJet Textiles (Germany) is marketing pretreated fabrics ready for inkjet printing.

A partial alternative to the pre-treatment of fabrics is the development of inkjet head technologies capable of using much higher viscosity inks. However, the ongoing need for some special preparation and pre-treatment of fabrics is probably unavoidable. Eventually, this may become as widely accepted if it results in significantly improved colour yield and reduced consumption of expensive inkjet inks. Novel preparative methods such as plasma treatment may also have much to offer in terms of primary adhesion and dyestuff fastness.

Fabric Feeding system

This system feeds and presents the fabric to the traversing inkjet heads, and ensures perfect registration and alignment throughout, even for delicate and unstable fabrics such as knits or fine silks. If required, this machine may also pre-heat and dry or set the printed fabric, before finally rolling-up the output smoothly and with even tension.

Machine vendors are increasingly focusing their attention on improved fabric feed and take-up mechanisms, as well as devices such as adhesive printing belts (fitted with washers to prevent a build-up of printed-through ink). Established screen printing manufacturers such as Ichinose and Zimmer are at the forefront of such developments. IMAGE PROOFER - Ichinose uses a conveyor belt to transport and align the textile substrate. The system is schematically shown in figure 6.

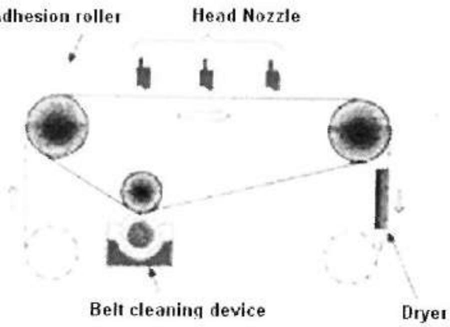

Figure 6 Ichinose-unit: conveyor belt and dryer

At the entry end the cloth is fixed to the conveyor belt with the help of suitable adhesive. The conveyor belt carrying the fabric gently moves ahead for inkjet printing operation. The print head nozzles are set up right above the carrier belt, and the cloth printed with the inks sprayed from the head nozzles. This can prevent the inks from bleeding onto the cloth. After printing operation the cloth at the exit end is released from the conveyor belt. The conveyor belt can be cleaned whenever necessary

Ink jet inks

Ink formulations for DP-applications are probably the most difficult problem that must be solved for further penetration of this printing technology in the textile industry. The inks comprising of pigments or dyestuffs of high purity must be milled to very fine particle size and particle size distribution. Inkjet inks must be formulated with precise viscosities, consistent surface tension, specific electrical conductivity and temperature response characteristics, and long shelf life without settling or mould-growth. Other important parameter is colour build up on substrate. The colorants must have very high strength and high chroma to achieve a broad colour gamut with a minimum number and amount of deposited colorant. In addition, further properties such as adequate wash-, light- and rub-fastness are necessary.

Reactive and acid dyes

From the outset, suppliers of textile inkjet inks were quick to offer products based on reactive and acid dyestuffs. Reactive dyes are particularly suited to cotton, viscose and other cellulosic materials, whereas acid dyes are used for wool, silk and nylon. Both are fully water soluble and relatively easy to formulate for a wide range of inkjet heads, especially the widely installed thermal drop on demand jet types.

Pigment colours and disperse dyes

Disperse dyes (for polyester and nylon) and pigments present a more difficult set of problems for ink maker. Both exist in water as dispersion of small particles. These inks must be prepared with high degree of expertise so that the particles will not settle or agglomerate (flocculate). The particle size must have an average of 0.5 micrometer and the particle size distribution must be very narrow with more than 99% of the particles smaller than 1 micrometer in order to avoid clogging of the nozzles

Since pigment printing accounts for over 50% of all conventional textile printing, it is an attractive target for inkjet developers. Several of the major jet ink producers have recently launched new pigment systems. Although still prone to some problems of handle and rub fastness, they offer excellent wash and light fastness and have the great advantage of universal application to almost all fibres and substrates. The major outstanding problem with their use in inkjet systems is how best to formulate and apply the resins which are required to bond the pigment particles to the fabric surface. Several different approaches, from spraying resin through a separate jet head to screen printing binder over an inkjet printed colour have been suggested. In the long run, improved resin technology seems likely to prevail, allowing trouble-free formulation and printing from a single inkjet head for each colour.

While reactive and acid dyes will always retain some place within the overall market (for example, for the brightness of shade, excellent handle and fastness offered by reactive dyes on cellulosics), it seems increasingly likely that disperse and pigment inks will represent the way forward for inkjet printing of textiles. Print head and machine design and materials handling arrangements will need to reflect this trend.

Spot colours versus process colours

The inks used in Conventional printing systems are known as spot colours. This means the required shade is prepared by mixing appropriate colours before printing. Although it is a skilled job, it allows matching the desired shade as closely as possible. The inks used in inkjet printing are known as process colours. The desired shade is produced on fabric itself during printing operation. This is achieved by super imposing the dots of limited number of colours essentially, cyan, magenta, yellow and black (CMYK). In some cases additional colours may be used to increase the colour gamut.

Fabric post processing

Post-treatments are associated with the printing operation; examples are baking, steaming and/or washing. These processes are similar to those for conventional textile prints, except that the process is undertaken with a much smaller batch size, typically a few tens of metres or even individual sample lengths.

One barrier to new entrants is the need to finish fabrics after printing, in order to develop and fix the colours to acceptable industry standards of wash, rub and light fastness, handle and appearance. Often there is a need for final application of flame retardency, soil, stain and crease-resistant finishes. Such processes call for the use of specialized capital equipment such as steamers, washers, driers, bakers and stenters. Aside from the cost and space requirements (water, energy, effluent etc.), many new potential users of inkjet technology have neither the know-how nor inclination to embark upon conventional textile processing in this way. Some suppliers of inkjet equipment or suppliers of pre-treated fabrics now offer small desk top steamers capable of handling short sample lengths of printed fabric (typically up to 30 metres). However, these are far from ideal for even small-scale production and still leave many aspects of fabric finish and performance uncontrolled, for example, shrinkage and final width.

SLOW ADOPTION OF DIGITAL TEXTILE PRINTING

Following issues are responsible for slow commercial adoption of digital textile printing.

- Existing machines do not fit the mainstream market needs.
- The existing speeds adequate for sample printing but not for bulk production
- Availability of printing inks at reasonable cost
- Colour matching problems in flat colours
- Reproducibility of results from one printer to another printer.
- Migration of manufacturing capacity to Asia
- Main stream textile printers are geared to low cost mass production business model and long response time
- Niche market has to be build up from scratch
- Educating the consumers about the potentialities of digital pointing

A VISION OF THE FUTURE

Applications for digital technologies may be analysed in three categories

1. Sampling This is the traditional application area and this may be expected to continue with modest growth.

2. Bulk production for batches less than 1000 metres. This is the vision of many and interest is at what point digital technologies can "compete" successfully with screen printing.
3. Mass-customization. The creation of new niche markets for small-medium batches of printed textiles for specific customers. It may be possible that garment makers decide to buy a digital printer and attach it to a laser cutting table. After printing, the fabric could be cut single ply using a computerized system and then converted to made-ups.

Major inkjet manufacturers are working to resolve the issue of production speed and it is hoped that inkjet printers will be available with a speed to compete with rotary screen printing. The ITMA 2003 exhibition in Birmingham, UK, was a significant milestone for digital printing, with 27 companies offering textile digital printing equipment. Many of the machines shown were said to print at over 50 m2 per hour, and the Reggiani printer was said to print at 150m2/hour.

The other possibility is that inkjet printing technology may be used as weaving technology where printers may have large number of inkjet printers like looms to carry out the printing production. In Bangkok a printing unit has 25 Stork Sapphire machines run much like a traditional weaving department.

CONCLUSIONS

Digital printing provides an opportunity to meet the present day market trends of mass customization. It has established as an acceptable technology for sample production. Among other technology problems speed of printing is the main hurdle in commercialization of technology. Attempts are being made to achieve commercially acceptable printing speeds. Till then the practice of combination of digital printing for sampling and rotary screen printing for production will continue. What now seems certain is that there is sufficient industrial investment and commitment by manufacturers to ensure that commercial ink jet textile printing will become a reality.

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Design Innovation And New Technologies

SANJAY GUPTA

Textiles have always played a central role in the evolution of human culture by being at the forefront of both technological and artistic development. Weaving was in fact the first industry to be fully mechanized; it was the catalyst to the Industrial Revolution and even today the possibilities continue to be created in hitherto undreamed areas as a consequence of the innovative technologies. The new technologies coupled with diversity of production techniques and plurality of styles and patterns that make up contemporary designer's vocabulary are fuelling Design Innovation.

Textile design today is influenced, on the one hand by major, broad-based industrial research projects into new fiber technologies for sportswear and industrial textiles, and automation and flexible manufacturing systems; and on the other hand by the constantly evolving consumer lifestyles.

This paper looks at the dramatic effect that new technologies are having on textiles, illustrating the current advances awhile adopting a forward-looking approach. People are living longer and spending more time on leisure activities. Added to that is the growing market for corporate-wear which, in some cases, is becoming increasingly fashion-oriented.

Industrial materials and techniques previously developed for completely different purposes are being utilized and expanded by textile artists and designers. The continuing concern for the environment claims the interest of those working with protective, recycled and responsive materials. Performance apparel represents one of the fastest growing sectors of the international textile and clothing industry. Not so long back it was the Technical textiles that were known for their performance and functionality whilst traditional textiles for their aesthetics! This distinction is no longer relevant. The two sectors have converged and increasingly, the so-called high-tech technical fabrics and apparel designed for high performance wears are crossing over the boundary into everyday fashion. It started with outdoor walking clothes and is moving more and more into the high street. Retailers are trying to distinguish their products from others, and to give a value-added feature to their fashions by means of technical fibers and finishes.

Typically, such specialty textiles use some specific technologies in addition to the conventional technologies so that the product would add value to a specific 'attribute' or function and/or effect. For example, in design of worsted black formal wear suiting fabric, which has a very deep black shade, the specific attribute is 'blackness'. If in the same fabric, hollow fiber is used to get a lighter fabric, the fiber will also add to the warmth and two additional attributes of 'lightness and warmth' get added. There are many such attributes, which can be broadly classified as under:

1. Aesthetic Effects (Visual)
   (Fiber blends, mélange effect, fancy yarns, surface treatments, woven textures, color development, dye-ability, patterns, luster etc)

2. Aesthetic Effects (Sensory)
   (Friction/ smoothness, bending, compression, fragrant etc)

3. Wearing Comfort
   (Weight, stretch, static charge dissipation/ reduction of clinging, slip-ability etc)

4. Comfort - Micro-climate control
   (Warmth, coolness, wicking of sweat, reduction of next-to-skin humidity & stickiness, breathable waterproofing etc)

5. Easy care
   (Dimensional stability, wrinkle resistance/ recovery, easy wash, easy dry, anti pilling, anti soil, moth proofing, anti bacterial)

6. Garment formability
   (Formability, sew-ability, non fraying, non-deforming etc)

7. Protective aspects
   (Hygienic- anti bacterial, deodorizing; Safety anti UV, healing, flame retardant; Environmental friendliness & non-toxic etc)

These attributes are however seldom used alone. The need in the professional clothing market is for complete systems to produce the required level of comfort, protection, care and looks. Designers today are working on fashionable collections containing complete system of technical attributes, from inner layers to outer. That's the way forward for high-value fashion fabrics.

Highlights of some recent innovations are given below under each attribute

Aesthetic Effects (Visual)

Schoeller of Switzerland is a prime example of a company that keeps a competitive edge by specializing in finishes and blends with a high-tech focus. Innovations for summer 2005 include ultra-light wind protection with matt sheen effects, bi-colour, high-sheen satins and color mixes. Many current Schoeller fabrics combine a mixture of these features, for example semi-transparent fabrics, bonded aluminums with metal sparkling effects in 3D structures, nano-sphere finishes or mirror and glow-in-the-dark effects. Metallics are used extensively in European collections for next year, from silver to metallic and aluminum to gold-vaporized fabrics.

Luminex is a new kind of fabric that glows, literally. It's not shiny, it's not glow-in- the dark; it actually gives off its own light. Designers took tiny, flexible optical fibers developed for high-energy physics experiments and wove them into ordinary fabric. Power comes from an ordinary battery sewn into the cloth. Luminex is being used in stage costumes, handbags and curtains as well as clothing. The makers are even talking about adding smart chips to the fabric that could make it glow in flashing patterns. Look for a line of silver Luminex pillows from DKNY next year.

Image 1. Luminex garments

Fluorescent and reflective yarns are also there. The fluorescent yarn emits light so that it glows in the dark. Reflective yarn is constructed using crystals embedded into its structure. The light falling on the crystals produces the reflection. The intended garment application is for club/night wear.

Tintoria di Quaregna s.r.l. has produced a range of finishes that give yarns unique performance qualities. "Stardust®" is a yarn finish, which gives the yarn a bright "twinkling" finished effect. The yarn's twinkling effect is better seen under bright lights, as when in the sun or under halogen lighting. This finishing effect can be applied to almost any yarn and can be washed away easily using a delicate washing programme.

Aesthetic Effects (Sensory)

Many technologies are available today that tend to soothe human senses. One of the most important technology in this area is micro-encapsulation. Microencapsulated fabrics are among the latest generation of fabrics known as intelligent fabrics, taking into account the functions they perform i.e. cosmetic, with a gradual release of active or volatile micro-capsules for cosmetic, therapeutic, energy-boosting, stress-busting, moisturizing or deodorizing, and, climatic fabrics with phase change microcapsules which are heat-regulating.

Microencapsulation is a simple process consisting of encapsulating liquid or solid substances in sealed micro spheres. These micro spheres which vary in size between 0.5 and 2000 microns, form a suspension of tiny droplets surrounded by a thin polymeric wall protecting the active agent before it is released. This wall or membrane is made by emulsion or dispersion of a natural or synthetic polymer in a carrier liquid. These microcapsules gradually release active agents by simple mechanical rubbing which ruptures the membrane.

Micro-encapsulation was introduced by fabric producers such as Welbeck (who were pioneers in the field) beginning with perfumery. There are a variety of fields of application: underwear and accessories (gloves, socks, hats, etc.) ready-to-wear, sportswear and casual wear, footwear, bedding (mattresses, eiderdowns, blankets, pillows etc.). Micro-encapsulation is also a feature of Penn Elastic's most advanced fabrics. Body-care encapsulation systems with Lycra, for freshness, moisturising and massaging are designed to persuade the wearer that they are receiving a beauty treatment as they wear it. Bayscent, from Bayer, brings micro-encapsulation of fragrances to many Penn fabrics. Riedel + Tietz are specialists in original aromatic fabrics: lilac, jasmine, lavender, lily of the valley, narcissus, peppermint, rose, violet, eucalyptus, camomile, banana, lemon, apple, vanilla, chocolate, pineapple, coconut…But also grilled meat, coffee, pudding, butter, gingerbread, mulled wine, marzipan, almond, nougat, petrol, incense, camp fires!!!!

Image 2. Fragrant Lingerie

Micro-encapsulation is also used in thermo-chromic fabrics i.e. Fabrics (woven or knitted) with colors which change, appear or disappear under the effect of variations in temperature. The fabrics themselves are not thermo-chromic, but the colourings are thermo-chromic and photo-chromic substances and liquid crystals are often microencapsulated, particularly for textile media. Thermo-chrome fabrics certainly aren't new, and the fact they have resurfaced today is spurred on by technological developments and in particular, by the success of micro-encapsulation. For the time being, their uses are relatively limited on the fashion market, restricted to the lingerie and swimwear sectors as well as to industrial clothing (protective and safety clothes).

Image 3. Thermochromic T-Shirts

Sensory effects are not just limited to specialised fibers and finishes. The seam-less structure of whole-garment making technologies using 3D weaving or knitting technology offers great new sensorial experience. An example is provided by the Wholegarment® machines produced by Shima Seiki Mfg., Ltd, which is one of the leading manufacturers of computerized whole glove and whole garment flatbed knitting machines. Their machines are capable of imparting a range of open and close structures, 3D effects and contrasting surfaces, to whole garments. The range includes entire garments including scarves, hats, jumpers, dresses, skirts, cardigans, tights, legwarmers and socks. If one combines those new developments in yarn with 3D knitting it is possible to make exciting new textiles for garments.

Image 4. Whole-garment by Shima Seiki

COMFORT

Fleeces were among the first fabrics to benefit from high-quality, high-tech approaches. Malden Mill's Polarfleece® is the original synthetic fleece fabric that forever changed the way the world dresses for cold weather. This fabric is soft, comfortable, provides warmth without weight, is quick drying and durable for long-lasting good looks. Its high breathability provides comfort in all activities and does not restrict the movement of moisture vapors. .

Technical fabric manufacturers such as Heathcoat of UK produce extreme-weather fleeces, which are used by the military, for outdoor workwear and also for recreational sports. Fleeces such as Polartec Wind Pro, Thermal Pro and Polartec 200 are also appearing in sports and leisurewear departments and Menswear retailers, who are marketing their extra qualities to consumers. Many of the fabrics, like Thermal Pro, are increasingly being customised, with different finishes available, such as water repellence. Complete moisture-management systems can be designed "*au choix*".

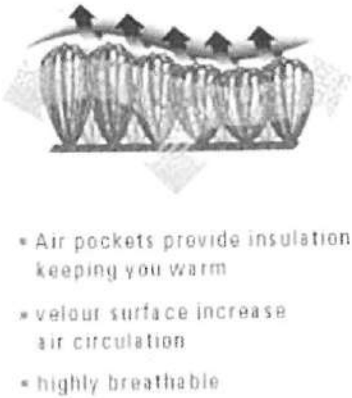

Image 5. Polar fleece

The latest on the scene is Polartec's Heat Technology that provides "Warmth on Demand®" during stop-and-go activities. Powered by rechargeable lithium ion batteries, Polartec Heat panels deliver three modes of user-adjustable warmth. These panels are very thin, lightweight, and flexible, and are designed not to interfere with a garment's function. They are also durable and machine washable. By providing warmth only when needed, this heating breakthrough reduces the need to add or subtract layers of clothing as weather or activity levels change. The panels are activated by the user and with a controller. When resting after a period of high exertion, the user turns the panels on. When resuming activity, the user turns them off, as the body's increased activity level provides the necessary warmth to maintain core temperature.

Image 6. Jacket incorporating Polartec's Warmth on Demand®

Phase change micro-encapsulation or OUTLAST technology offers another way of maintaining body heat. The chemist introduces a paraffin hydrocarbon-based phase change material, as it is known, into plastic shells. In contrast to microcapsules destined for cosmetic textiles where the membrane must be flexible enough for gradual release of the product, the shells used for Outlast are hard; to protect the paraffin based substance from external elements. Approximately 1,000 microcapsules can fit on a single pinhead. The PCM (phase change material) is ultra-sensitive to temperature variations. Below 37° the PCM remains in its solid state. Above this temperature it turns to liquid storing surplus body heat. It can then change state an unlimited number of times. When it solidifies again, the PCM releases body heat stored in the plastic shells and distributes it evenly around the body. This re-heating effect can last several hours but it is necessary to regularly activate phase changes passing through periods of re-heating (more or less intensive activities) and cooling. Fabrics containing PCM microcapsules are capable of storing at least 10 times more heat than untreated products.

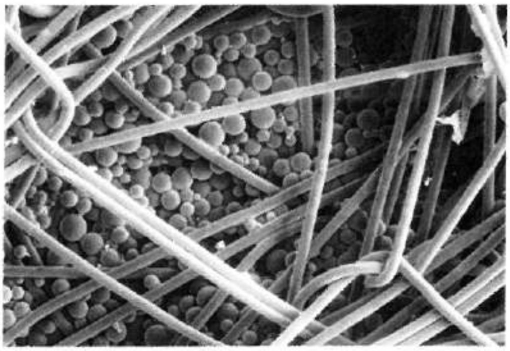

Image 7. PCM microcapsules

A new range of yarn called "Extended Function" consisting of Polycolon® allows the body to stay drier for longer periods under heavy body perspiration. Polycolon® yarns are about 40 per cent lighter than cotton, and perform by quickly conducting moisture to the absorbent surface layers from where it gets evaporated.

Easy Care

Teflon and similar treatments are used both as a stain-repellent and stain-release mechanism, prolonging the life of a garment and making it more saleable. Translated into the fashion arena, Teflon on suiting fabrics is becoming a selling point, found at all levels of the market, with the increased cost apparently easily absorbed by the end users and also recognized on swing tickets. DuPont's Teflon® can now also be applied to all types of yarn. The coating is invisible, it does not affect the yarn visually or physically, is breathable and has easy care properties.

Nanotechnology is, however the new buzzword for the moment in almost all industries. Schoeller has a NanoSphere finish that is water-, dirt- and stain-repellent and can be applied to a diverse range of fabrics, giving an extra dimension to fashion fabrics. Water simply runs off the nano-surface of clothing nor can staining substances such as ketchup, honey, coffee or red wine take hold. And even if they fail to run off of their own accord, the stain can easily be rinsed off under running water. The first products from top garment manufacturers as Berghaus, Bugatti, Hugo Boss, Mammut or Polo Ralph Lauren are being presented at the current fairs.

A new elastic fiber with Lycra brand, T-400™ has revolutionized the comfort, hand, stretch and recovery, wrinkle-resistance, wash ability and care of contemporary fabrics. This includes synthetic woven, denims, lightweight cotton, wool and poly/cottons. As shown in the photos below, T400 has uniform crimp, resulting in knitwear with a clean, smooth appearance. Garments have clear stitch definition and a beautifully soft handle versus knits made with textured yarns.

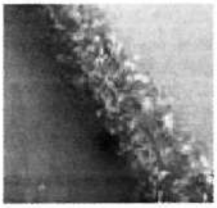

Image 8. T-400 has a uniform crimp as against a normally textured yarn.

Image 9. Wash effects on T-400 denim jeans

Garments with T400 keep their shape, even after repeated washing and wearing. Sweaters resist bagging at the elbows so they look new and feel great. But it is really the denim jeans that provide the best opportunity for use of T400. Since T-400™ is chlorine resistant it can withstand a variety of bleaching and washing conditions that are not typically used on stretch denim. The latest treatments, such as antique finishes, whisker washing and sandblasting can be applied to garments with excellent results. What's more, it can even give a more tailored look as the jeans hold a crease wash after wash. Jeans containing this fiber are among the most comfortable as T-400™ provides a subtle stretch for comfort and ease of movement. Garments not only fit well, but retain their shape wear after wear.

Garmenting process is also eased as fabrics with T-400™ have minimum shrinkage thereby simplifying the cutting and sewing process. Garments stay true to their original size for enhanced consumer satisfaction.

PROTECTIVE ASPECTS

The protective aspects of textiles have provided the most fertile ground for innovative developments. While the developments have focused on environmental protection and personal hygiene, it is the medical and therapeutic aspects, which have really caught the fancy of lifestyle product manufacturers.

The wide scope for encapsulation in fabrics has allowed moisturizers, therapeutic oils such as Aloe Vera, or even insecticides for tropical climates to be incorporated into fabrics. Buzz Off, in the US, is a chemical treatment to prevent mosquito bites, originally a military invention that is now being sold worldwide for cotton fabrics destined for holiday clothing. Made from permethrin, a man-made form of the all-natural insect repellent derived from the chrysanthemum plant. Through a patent-pending process, Buzz Off insect shield apparel by Orvis provides protection from biting insects for the useful life of your clothes.

Meanwhile, encapsulation and medical research moves on, centered around the delivery of medicines and drug treatments through clothing, perhaps overnight, to patients.

Antimicrobial treatments began as useful adjuncts to measures to cut down MRSA, the pervasive and pernicious hospital super-infection. Eschler, for instance, is producing a range of Trevira Bioactive fabrics for use in the medical field. Its potential for use in sportswear, underwear and workwear was soon recognised and now it is becoming a common treatment for fashion clothing. Trevira Bioactive was recently made effective for socks, a prime target that has been difficult to achieve, and there is great interest in this area. Underwear is branded at point of sale with labels such as Silfresh, Trevira's Bioactive, or Amicor, as it has been found that customers recognise and value such quality marks. Technical yarns such as Meryl Skinlife for bacteriostatic qualities permanently contain the active substance in the polymeric matrix.

Image 10: Trevira Bioactive garments for hospitals

Sanitized® is a yarn which has an antibacterial effect. Its development was encouraged by the difficulty of eliminating bacteria from clothing. Sanitized® works by blocking the cell walls of the bacteria and cause them to starve, keeping the garment fresh and hygienic. Lenzing Fibres has launched a new lyocell microfibre based on Lenzing Low Fibrillation technology, allowing the ultra-fine fabrics to be processed like conventional cellulose fabrics, producing fine, soft fabrics with low allergic properties.

Image 13. Anti microbial property of Sanitised fiber

Ingeo™ fiber (made by Cargil Dow out of corn polylactide fiber) combines the qualities of natural and synthetic fibers in a new way. Ingeo fiber is naturally flame retardant and has good moisture management characteristics. This means that Ingeo fiber is ideally suited to fabrics from fashion to furnishings. It can produce a whole unique new family of compostable products without compromising performance. Imagine a disposable diaper that is also completely biodegradable so that no waste is left to contaminate the earth. Already, light, hypoallergenic duvet and other bed products made of this worlds first man-made fiber from 100% annually renewable resource are being offered in the market

Image 11. Ingeo hypoallergenic bed products

Schoeller's S-Shield® is a high-performance worsted spun yarn, which protects the body against electronic radiation by incorporating very fine stainless steel fibres in the range of 3-50 per cent, depending on application, with wool, polyester, aramid, viscose or polyamide.

Incorporation or metallic fibers in textiles have other medical and therapeutic purposes. The use of silver for medical and therapeutic purposes has been known about for many years, ever since the "magic health properties" of silver were discovered. Modern medicine has found silver to be a very effective, natural anti microbial element when used in wound dressings, bandages, underwear and apparel textile materials. The appropriate use of silver properties in textile structures provides also an opportunity for obtaining suitable thermal conditions. Silver also possesses electro-conductive and electrostatic properties. Using the above-mentioned silver properties in textiles is of interest to many fibre, yarn and textile producers. Yarns with silver content can be produced either as a silver-core spun or with pure silver coatings.

Qoperfina® Copper yarn combines the finest combed organic cotton with pure and natural Angelina copper staple fiber, an intimate blend yielding an incredibly soft, durable and healthy fabric with both fashion and therapeutic properties. This high-tech performance is suitable for knit and woven applications, including apparel, intimate wear, socks, home textiles and furnishings, bed and bath.

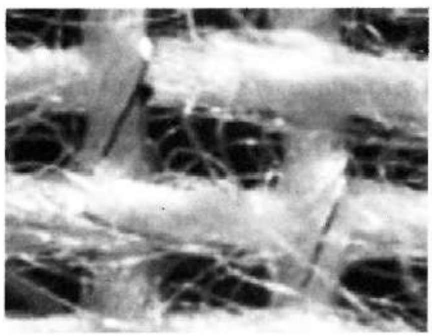

Image 12 Copper filament containing yarn

Cellulose is a polymeric derivative of sugar, which when allowed to react with certain compounds gives substituted celluloses that then contain substituents with chelating reactivity that bond Cu. When this fiber is placed in contact with the skin, amino acids and other chelating agents in the *Stratum corneum* form Cu complexes by ligand exchange and these complexes are absorbed through the skin, producing many useful pharmacological effects as a result. These include, but are not limited to, relief from rheumatism, arthritis and stress. Copper containing fibers can protect the human body from harmful electromagnetic frequencies and facilitate the recovery from harmful electromagnetic radiation.

Deodorising is another area of interest. Developments include "Smellkiller®" fibers that can get rid of any unpleasant odours such as smoke, oily smell as well as perspiration. Light is used to stimulate the yarn by triggering a photo-catalytic reaction to release the deodorising material in the fibre. It is claimed that a small amount of light such as a 30W bulb can stimulate the yarn to absorb almost any unpleasant odours.

CONCLUSION

These are just a few of the possibilities that new emerging technologies are opening for innovative textile design. The barrier that kept traditional and technical textiles separated is broken and convergence is underway. That's the way forward for high-value fashion fabrics.

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Innovation In Dyeing

ROLF ROOS, PIERRE GALAFASSI,
ATHANASSIOS TZIKAS & SIEGFRIED SANTAMARIA

A competitive dyeing operation is a prerequisite for survival in today's industrial environment. It is essential to strike the right balance between the cost of chemicals, including dyes, and dyehouse productivity, which depends mainly on lab-to-bulk and batch-to-batch reproducibility and on speed and reliable supply. Choosing the apparently most economical dyes can make a dyehouse less competitive rather than more so. Ciba Specialty Chemicals offers an overall concept, leading to a better balance of the key elements in total costing, based on dye segmentation according to shade depth and required fastness.

EXHAUST DYEING OF COTTON AND ITS BLENDS WITH REACTIVE DYES

Basing their calculations on superficial analysis of the main influencing factors in the total cost of dyeing, dyehouses today often choose the apparently most economical dyes, irrespective of the shade depth required and of the compatibility of the dyes. This often results in a selection of dyes from different ranges with different affinity and reactivity. While many dyehouses need to be much more competitive, this recent trend can actually reduce competitivity. Improving shade reproducibility is essential to ensure higher competitivity.

Ciba Specialty Chemicals offers a concept for reactive dyeing that allows a better balance of the key elements in total costing, based on dye segmentation according to shade depth and required fastness ("usual" or "special") (fig. 1):

- The polyreactive and highly compatible CIBACRON® FN warm dyeing range is recommended for pale to medium shades as well as those known to be particularly difficult to reproduce, such as beige and grey, which are only really competitive if they have superior reproducibility.

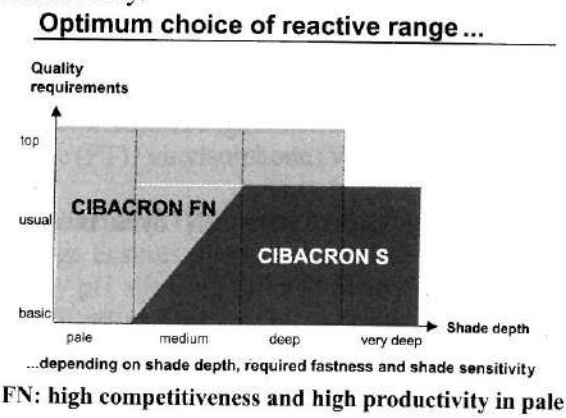


Figure 1: CIBACRON FN: high competitiveness and high productivity in pale and medium shades

- Recently launched, patented and highly innovative, CIBACRON S dyes, together with CIBACRON Super Black R and CIBACRON Super Black G, are recommended for deep, very deep and black shades, where lower colouristic costs, yet superior build up are an absolute must in order to achieve high competitivity. These dyes achieve the fastness standard normally required.

- CIBACRON FN dyes are recommended for deep shades requiring special, non-standard fastness properties.

In all pale and medium shades and in particular in difficult trichromatic shades (including grey, beige, brown, khaki, earth tones), the crucial factor in achieving superior cost competitivity is shade reproducibility, short dyeing cycles coming a close second. The costs of correction through shading, stripping and re-dyeing (or levelling out) are very high indeed and further increased if the impact on prompt delivery, customer satisfaction and, in some cases, fibre appearance and/or handle are taken into account (fig. 2). Reducing the frequency of re-dyeing and shading has far more impact on the competitivity of a dyehouse than systematically selecting the cheapest dyes on the market in this shade area.

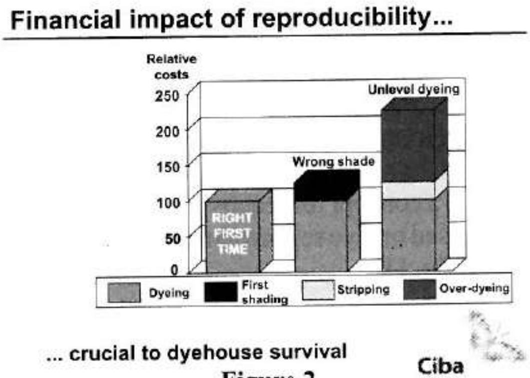


Figure 2

CIBACRON FN polyreactive dyes owe their high popularity in large part to their unique level of reproducibility in those shades where it most matters, i.e. pale and medium, and to the very short dyeing cycles allowed by their compatibility and solubility. Their popularity is also due to their high fastness, which includes special fastness specifications recently introduced, such as wash fastness at 95°C, fastness to repeated washing, chlorine fastness, light fastness in pale shades and perspiration light fastness.

The outstanding reproducibility of CIBACRON FN dyes is due to a combination of advantages:

- Extremely high compatibility of the dyes due to similar affinity, similar speed of diffusion and similar reactivity of the dyes when used together.
  Frequently, too little attention is paid to this fundamental aspect of dye compatibility. In

most ranges the same reactive group (or pair of reactive groups) is used for the whole range, without taking into due consideration the widely differing electron-donating properties of the various chromophores and <u>thus their high impact on speed of reaction</u> (reactivity) (fig. 3).

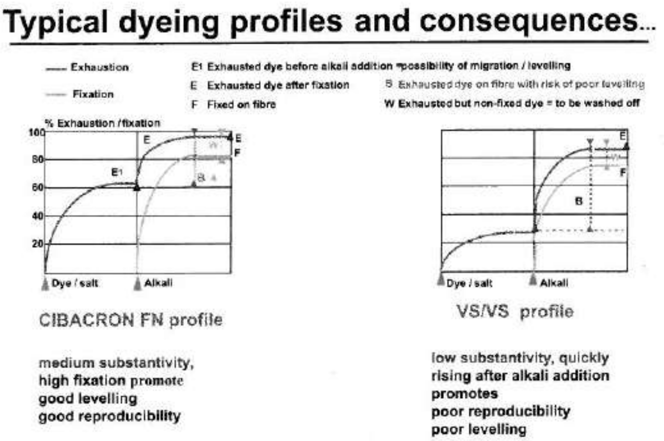


Figure 3

In the CIBACRON FN range, Ciba Specialty Chemicals' R&D team has matched the chromophores with the right pair of reactive groups, choosing from 5 different reactive groups (3 of them unique to Ciba Specialty Chemicals) for each dye, to obtain dyes with similar reactivity and affinity.

- Narrower strength and shade variation tolerance limits in standardization of each dye in range than the usual standard in the industry.
  CIBACRON FN commercial forms are standardized to within +/- 2% in strength. Reactive dyes are encountered on the market with tolerance margins of +/- 3%, 4% and even over 5%!

- A logical choice of the pair of reactive groups, limiting the impact of the unavoidable variations of dyebath pH and temperature on dyeing results.
  The difference between choosing the right and a less-than-optimum pair of reactive groups becomes clear when comparing for example the classic monochlorotriazine/ vinylsulphone (MCT/VS) combination with one of the pairs used in the CIBACRON FN range, the fluorotriazine (FT) / vinylsulphone (VS) combination:

- the combination of fluorotriazine (FT) with any of the three types of VS reactive groups used in the CIBACRON FN range ensures good reproducibility, because FT has slightly higher reactivity than VS. Thus any pH allowing full and dependable fixation of the VS group also allows full fixation of the FT group. Furthermore, since the bond formed between FT groups and cellulose is completely stable under alkaline dyeing conditions, this fixation is also stable (no destruction of the existing bond).

- the conventional pair of reactive groups monochlorotriazine/vinylsulphone (MCT/VS) yields a few good dyes. However, this combination is prone to problems of reproducibility in some important dyes, since in this case the MCT group has significantly lower reactivity than the VS group. A higher pH is therefore required for full fixation of MCT, but this impairs the notoriously alkali-sensitive bond just created between VS group and fibre.

CIBACRON S, CIBACRON Super Black R and CIBACRON Super Black G

The profile of an ideal dye range for deep and ultra-deep shades differs quite significantly from that of an ideal dye range for pale and medium shades. Using the same type of dyes for pale/medium and deep/ultra-deep shades is a costly compromise in terms of competitiveness and productivity. Safely achieving the level of fastness required by the particular dyehouse, with the highest productivity at the best overall cost is key for success.

The new CIBACRON S range and CIBACRON Super Black R and CIBACRON Super Black G ensure high competitiveness and productivity in deep and very deep shades, including the deepest blacks, which were formerly only attainable with sulphur dyes.

Deep and ultra-deep shades are somewhat less demanding than pale and medium shades in terms of dye compatibility. Some fastness properties (light, chlorine, etc.) are also easier to achieve without the need for exceptionally suitable chromophores. However, deep shades are much more demanding in terms of

- colouristic cost of the dyes: in deep shades dye costs have a major impact on total dyeing costs, which is even more significant than the impact of reproducibility costs
- build-up in deep shades: dyes approaching their saturation point in deep shades show a disproportionate increase in required concentration, and therefore become very costly and in some cases even fail to achieve the required shade depth or achieve it so narrowly as to cause significant reproducibility issues. It is, for example, well proven and documented that black shades frequently cause reproducibility problems, mainly due to the limited build-up of the required shading components!
- speed of diffusion and washing-off: rapid levelling and, more especially, quick washing-off of unfixed dye, help greatly to speed up the process and are therefore key for productivity.
- solubility in the dyebath: poor solubility, quite frequent in these high dye concentrations required for deep shades, impairs levelness and shade reproducibility; high solubility is particularly required in modern ultra-low-liquor-ratio jets and allows their potential for highest productivity (very quick dyeing and washing cycles) to be fully exploited.

Ciba Specialty Chemicals research teams have developed (patents pending) a completely new principle for cost-effective dyes with extremely high colour strength, by combining 3 specific chromophores engineered in such a way as to give these molecules high flexibility and optimum, i.e. medium, substantivity, thereby ensuring good diffusion and increasing washing-off speed, and by choosing the right 3 (2 in some cases) reactive groups for each group of chromophores (fig. 4):

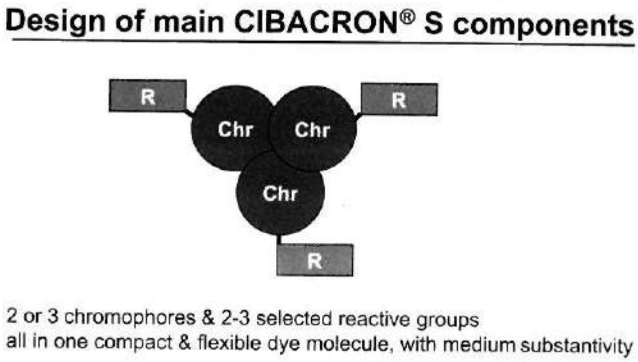


Figure 4

Ciba

This special design allows the creation of very strong chromophores, which give high fixation and are ideal for cost-effective dyes for deep and ultra-deep shades.

CIBACRON S

CIBACRON S dyes are especially designed to allow exceptionally high build up with very low amounts of dye, in some cases creating a completely new state of the art. These dyes allow cost-effective production of deep and very deep shades that either cannot be attained at all with conventional reactive dyes or require twice or three times the amount of dye (figs 5 and 6):

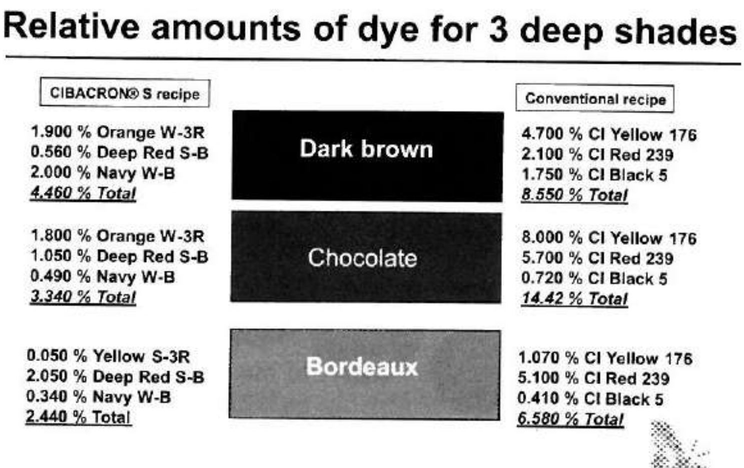


Figure 5

Ciba

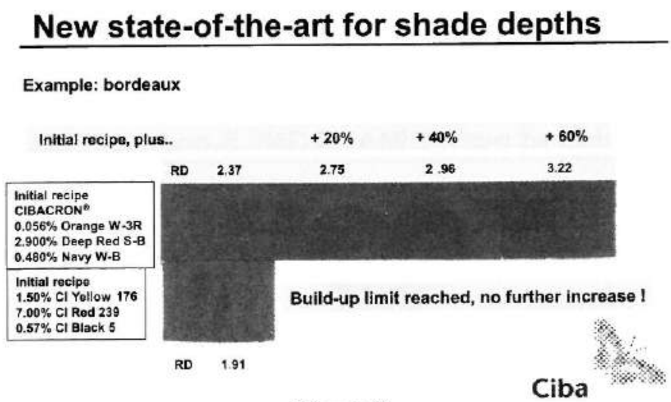


Figure 7

CIBACRON S dyes are also compatible with one another in di- and tri-chromatic systems. Even though dark shades are less demanding than pale shades from this point of view, compatibility remains an important parameter in productivity and reproducibility.

In these deep and very deep shades, full and very quick washing off of unfixed dye is a very important parameter, impacting the level of fastness achievable, especially wash and contact fastness, such as perspiration fastness. CIBACRON S achieves all the most important standard fastness properties required for the large majority of uses.

CIBACRON Super Black R & CIBACRON Super Black G

Ciba Specialty Chemicals has also created a new state of the art for deep and ultra-deep black shades. CIBACRON Super Black R and CIBACRON Super Black G allow the deepest black shades, until now only feasible with sulphur dyes, to be attained with reactive dyes, which are not subject to the well-known limitations of sulphur blacks (fig. 7).

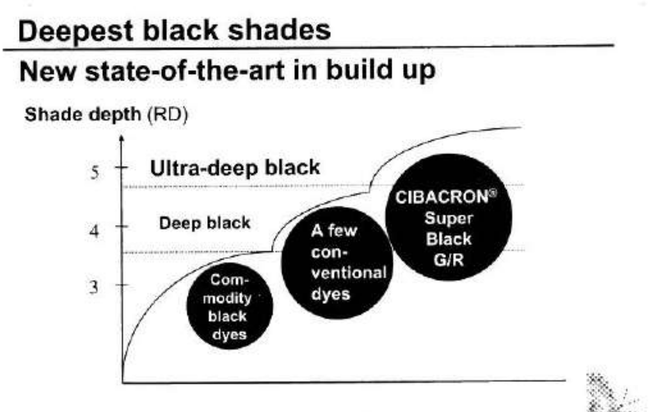


Figure 7

The unique build up of these dyes is due to the creation by Ciba Specialty Chemicals R&D of several new (patented) orange, red and brown components.

A particularly attractive feature of CIBACRON Super Black R & CIBACRON Super Black G is substantial simplification of recipes for different black shades.

It is well known in dyehouses that shading a black reactive towards a greener, bluer or redder shade to fulfil particular market requirements frequently causes problems, including:

- a significant increase in cost: the usual yellow and red shading components are much more expensive than the black basic dye mix and it does not take much shading component to offset the recipe cost.
- decrease of reproducibility, since the usual shading components have limited build-up and often work near or at their saturation level.
- increasing risk of poor washing fastness: the shading component always being inferior in wash fastness to the main black component.

By selecting either the greenish version, CIBACRON Super Black G, or the reddish one, CIBACRON Super Black R, or by mixing the two dyes as required, dyers can ensure simple, robust and cost-effective production of all shades of black.

The previous generations of black reactive dyes have medium light, chlorine, and rubbing fastness and sometimes also wash fastness. This borderline fastness is accepted for most articles by the industry as "the standard", and "impossible to improve except with higher dye costs". However, numerous brand houses would welcome somewhat better fastness, provided costs did not increase significantly.

CIBACRON Super Black G and CIBACRON Super Black R can achieve better fastness performance than commodity, C.I. Black 5-based reactive black dyes. Very poor rubbing (crocking) fastness is one of the most frequently heard complaints about black shades. Sulphur dyes usually give the worst results, but reactive dyes are also rarely satisfactory.

CIBACRON Super Black R and CIBACRON Super Black G, which benefit from unique build up and outstanding washing off performance, frequently meet rubbing fastness requirements where other black dyes fail. (A dye-independent factor, the brittleness of fibrils, also plays a significant role in poor rubbing fastness.)

As mentioned, CIBACRON Super Black R and G have exceptionally good washing-off behaviour, the new orange, red and brown components behaving just as well as the navy component in terms of fixation, build up and diffusion rate. This is clearly demonstrated by the on-tone (pale grey) colour of all the rinsing and washing baths of CIBACRON Super Black G and CIBACRON Super Black R. Previous generations of black mixes showed an orange or reddish soaping bath, demonstrating the incompatibility (lower fixation, poorer diffusion) of some components.

CIBACRON S dyes, together with CIBACRON Super Black G and CIBACRON Super Black R, set a new standard in cost-effective dark and black shades for a wide field of cellulosic end products. These dyes can be used in conjunction with pretreatment processes such as Ciba® SMART PREP and finishes such as Ciba® ULTRAPHIL® moisture management to achieve successful textile solutions. To help customers obtain the required results, Ciba Specialty Chemicals provides a wide range of products and technical services, including color matching.

Innovation In Polyester Dyeing

Today's lifestyle, fashion trends, and concern for health and the environment are among the factors that have led to an ever-increasing demand for outstanding wash fastness on polyester and its blends. Launched more than 25 and 15 years ago respectively, the first two generations of "washfast" disperse dyes had serious limitations as regards fastness, shade and/or application properties. Ciba Specialty Chemicals' research team has now succeeded in developing an innovative range of completely novel disperse dyes based on a new, patent-pending and registered phthalimide azo chemistry. Ciba® TERASIL® WW dyes are distinguished by outstanding wash fastness on polyester and its blends, even under very severe washing conditions, and they cover the full shade gamut.

Why demand for higher wash fastness is rapidly increasing
The rapid rise in demand for high wash fastness of shades on polyester and its blends is due to a combination of factors:

- more multicoloured sports-, leisure- and even workwear, with contrasting colours. These contrasts markedly increase the risk of visible bleeding from one colour into other, adjacent ones.

- the growing popularity of polyester microfibres, for both clothing and upholstery. To achieve a given shade depth, microfibres require 3-5 times more dye than the coarser conventional polyester fibres. This explains the much poorer wash fastness obtained (more dye on surface more bleeding).

- the use of finishing and softeners, which significantly enhance extraction/bleeding of disperse dyes.

- the popularity of polyester/cotton blends; disperse dyes tend to soil cotton during the dyeing process and bleed heavily during laundering.

- the growing popularity of polyester/ ner blends; the strong adsorption of disperse

- a severe washing test (for example AATCC 61, 2A) and/or

- a critical substrate or blend (for example polyester/cellulose, polyester micro, polyester/elastomer...) and/or

- a deep shade

The second generation of washfast dyes truly deserves this qualification: the very bright red dibenzofuranones achieve outstanding wash fastness results, even under very unfavourable conditions.

Unfortunately, the first born in the dibenzofuranone family, C.I. Red 356, had rather poor dyeing behaviour, especially non-reproducible build-up and very high sensitivity to fluctuations in dyeing temperature, making it difficult to produce deep shades.

These dyes were superseded a few years later by improved dibenzofuranone reds, which all exhibit very good dyeing behaviour. However, two major disadvantages subsisted:

- only red can be produced with dibenzofuranone dyes; no other shades are attainable.

- coloristic costs are very high, which is particularly unfortunate since wash fastness needs improving mainly in the deepest shades, which require high amounts of dye.

Fig. 3 Comparison between commodity, first generation and second generation dyes. on PES/CO (67/33), post set 30s at 180°C; same colour strength (1/1 standard depth); AATCC 61, 2A, 49°C (severe conditions).

	1/1 SD	CA	CO	PA	PES	PAN	WO
Commodity dye	Disperse Red 167						
First generation	Disperse Red 311						
Second generation	TERASIL Red W-BF 200%						
First generation	Disperse Blue 284						

Created in the 1990s, the Ciba® TERASIL® W (Washfast) disperse range featured, besides a second-generation dibenzofuranone red with ultra-high wash fastness (TERASIL Red WW-BFS 200%), a number of patented, improved first-generation washfast dyes: TERASIL Red W-4BS, TERASIL Red W-RS, TERASIL Navy W-RS and TERASIL Black W-NS.

The coloristic costs of all these new dyes did not exceed those of the reasonable first-generation dyes and they had better washing performance than the pioneers Disperse Blue 284 and Disperse Red 311 (Fig. 4).

Fig. 4 PES/CO (67/33), dyed and post set for 30s at 180°; same colour strength (1/1 standard depth); wash fastness test ISO 105C06, C2S, 60°C.

1/1 SD	CA	CO	PA	PES	PAN	WO
Disperse Red 311						
TERASIL Red W-4BS						

However, under tough washing conditions, even these improved first-generation washfast dyes only fulfil some of the market requirements. What the market really wants is: "a range of reasonably priced disperse dyes, covering the whole shade gamut (and not only reds, as with dibenzofuranones), with outstanding wash fastness, as assessed in all the usual wash fastness tests, including severe ones such as AATCC 61, 2A, on all types of polyester and its blends."

Ciba Specialty Chemicals' R&D team was the first to identify and implement a chemistry, of the phthalimide azo family, that fully achieves the required profile.

The new range of patent-pending TERASIL WW dyes is now being launched worldwide.

Very popular in USA and increasingly used worldwide by all dyehouses exporting to USA, the severe AATCC 61, 2A test is a very good judge of wash fastness. (The slightly less severe ISO 60°C and M&S 60°C washing tests are standard requirements for polyester dyed in or exported to Europe.)

Figure 5 shows a comparison of new TERASIL WW dyes with representatives of first-generation washfast dyes, tested under AATCC 61, 2A (Fig. 5) washing conditions, in strong shades, on a polyester/cellulose fabric.

Fig. 5 Dyed at the same strength (1/1 standard depth for colours, standard navy and black shades) on PES/CO (67/33), post set for 30s at 180°C; wash fastness AATCC 61, 2A, 49°C.

WW dyes					
TERASIL Yellow WW					
CA	CO	PA	PES	PAN	WO
TERASIL Scarlet WW					

1st generation					
C.I. Yellow 114					
CA	CO	PA	PES	PAN	WO
TERASIL Red WRS					

dyes by elastomers during the dyeing operation is followed by equally marked bleeding during subsequent laundering of the garment.

- increasing awareness on the part of fashion houses of the particular wash fastness properties of dyed polyester, with its high sensitivity to small washing temperature differences in the 30-60°C range. To avoid complaints, fashion houses tend to request higher, more dependable, fastness standards.

- concern about potential health risks related to poor wash fastness combined with a growing tendency to wear pure and blended polyester garments next to the skin (higher exposure) and the hydrophobic nature of disperse dyes (affinity for body fat).

Fig. 1Wash fastness of C.I. Disperse Red 167 (colour strength 1/1 standard depth) on various substrates; post set for 30s at 180°C.

ISO 105-C06 C2S, 60°C, multifibre strip

Substrates	CA	CO	PA	PES	PAN	WO
100% PES						
PES/CO						
PES micro						

The various definitions of "good" wash fastness

Poor wash fastness always has one cause the presence on the polyester fibre surface of traces of dye, which have either resisted the reduction clearing treatment that usually follows dyeing, or, more likely, have thermomigrated from the inside back to the surface of the fibre during the essential heat treatments that follow dyeing (post-setting, resin finishing, drying, hot pressing, etc.).

The wash fastness performance of a particular textile depends very closely on the conditions chosen for the test. It is therefore highly advisable in any discussion on wash fastness to agree first on the test conditions, to determine how well they correlate with reality and to ascertain whether they allow potential problems to be predicted.

The following test conditions greatly affect the result:

Temperature of the washing bath

Most disperse dyes on the surface of the polyester fibre do not significantly stain adjacent colourless material as long as the temperature remains below 40°C. An increase in temperature of only 5-10°C, however, is sufficient to impair performance, especially in tests involving rigorous mechanical treatment, such as AATCC 61, 2A, 49°C. Bleeding is still more pronounced if the temperature is increased by a further 15-20°C (Fig. 2).

Type of adjacent colourless testing textile

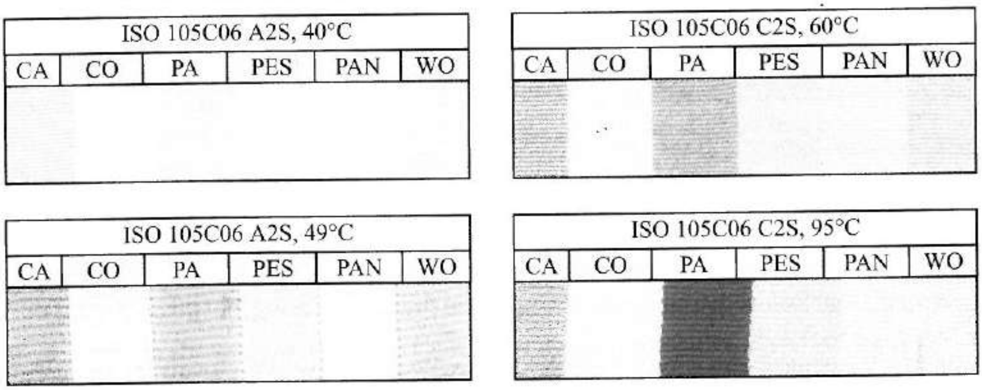
The commonly used multifibre strip (containing polyamide, polyester, secondary acetate, cotton, acrylics and wool) is an efficient bleed detector. The polyamide and secondary acetate fibres are the first to pick up any loose disperse dyes.

Some tests involve the use of only polyester and cotton as adjacent fibres. These fibres are much less sensitive than the others and often do not reveal potential problems, except at the very high washing temperatures (over 70°C) typically used for workwear, for example.

Relative quantity of coloured test fabric and adjacent material

Some wash fastness tests, those used for workwear for example, specify coloured and colourless fabric in a ratio of 50 (coloured) to 1 (colourless), massively increasing detection sensitivity of bleed.

Fig. 2Wash fastness of C.I Disperse Red 167 (1/1 standard depth) on PES/CO (67/33), post set 30s at 180°C. Wash fastness tested under various standard conditions.



WASHFAST DYES: A BRIEF HISTORY

The first generation (C.I. Disperse Red 311 or Blue 284 for example) of "washfast" dyes, born about 25 years ago, only just deserves this qualification. The wash fastness of these dyes is certainly higher than that of the best classical commodities (such as C.I. Red 167), but it is still very limited. Good fastness ratings cannot be obtained where the following factors are combined:

A New Approach To Obtain Cotton Like Comfort In Polyester

AM THAKARE & HEMLATA NIGAM

To improve on some undesirable properties of polyester, the polyester fibres (1.4 denier, 44 mm) were treated with different chemicals at optimum temperature, optimum concentrations (on the weight of fibre) for fixed duration and then dyed with disperse dye are spun into yarn with constant parameters and woven into fabric using all the double yarn samples. Some of the characteristics viz, weight loss, fibre denier, fibre surface, strength, moisture regain %, and dye yield of fibre are studied. Fabric were woven from the yarn spun from the fibres which shows better properties with reference to dye uptake, moisture regain, tenacity etc. Then studied various fabric properties like flexural rigidity, pilling, drape, tensile strength, tearing strength, moisture regain %, crease recovery, fabric thickness, fabric weight in gram per meter square, abrasion resistance. Fabric draping quality, air permeability, abrasion resistance, moisture regain %, handle, dye yield, lustre etc are found enhanced and reduced pilling tendency due to the surface modification of polyester fibre after treatment with different chemicals at fibre stage. Improvement in such properties can help to get cotton like comfort in garments.

In today's market situation in India the polyester use is steadily increasing as compared to cotton and other fibres. The major thrust in research and developments in textile is for cellulosic and polyester material. Among the synthetic man-made fibres, the polyester is having the largest share in market. Due to low price, durability and fashion look polyester finds growing use in domestic and to some extent in export market.

Some undesirable properties like less moisture regain, static charge build up, tendency to pill, less comfort to wear, unpleasant handle, lack of drape and feel, low bulk etc. are the factors causing less use of polyester apparels in tropical countries like India. While cotton having more comfort properties and no undesirable properties like polyester, its apparel is being used too much extent globally. But due to some excellent properties such as high strength, abrasion resistance, dimensional stability, wear resistance, easy-care properties, chemical resistance, long durability, wrinkle free characteristics and resistance to moth, mildew and micro-organisms use of polyester shows upper hand like cotton in apparels.

To improve on properties of polyester, various developments and innovations have been done from manufacturing fibre to fabric processing stage, and some more are being done in industries and institutes.

The surface modification of PET fabric by sodium hydroxide and other chemicals are reported earlier. However, little work has been reported on treatment at fibre stage to improve on properties in polyester. In this contest attempts are made in this study to modify the surface characteristics of polyester fibre by different chemical treatment at different temperatures on fibre stage. To study the changes in fibre properties of polyester, it is treated with various chemicals like Sodium Hydroxide, Zinc Chloride, Benzoic Acid, Maleic Anhydride.

Experimental

Fibre Specifications

Fibre type	-	Polyester
Fibre cross-section	-	circular
Fibre linear density	-	1.4 D
Fibre length (mm)	-	44

Experimental Plan

The various steps were involved in the present study, are given below

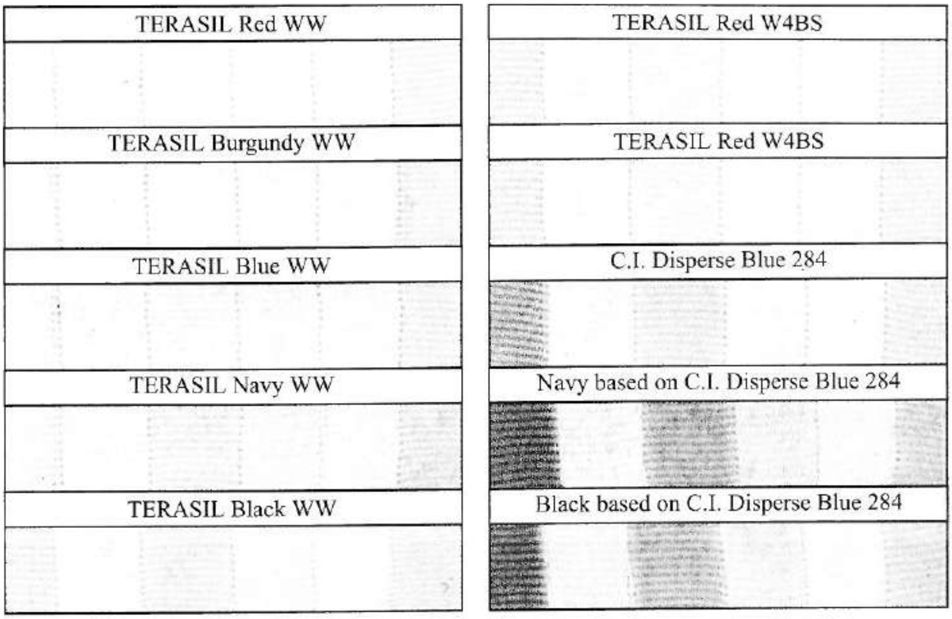
Step 1 - Treatment of polyester fibres with various chemicals at different concentrations and temperatures for fixed duration.
Step 2 - To study fibre properties and compare it with untreated fibre.
Step 3 - To do dyeing of it and compare dye yield.
Step 4 - To spun yarn from dyed fibres from those having optimum moisture regain, tenacity and dye ability.
Step 5 - To weave fabric from it and to check various f abric properties including aesthetic appeal.

Experimental methods

Treatment of polyester fibre with caustic at fixed concentration and fixed duration at different temperatures to optimize temperature.

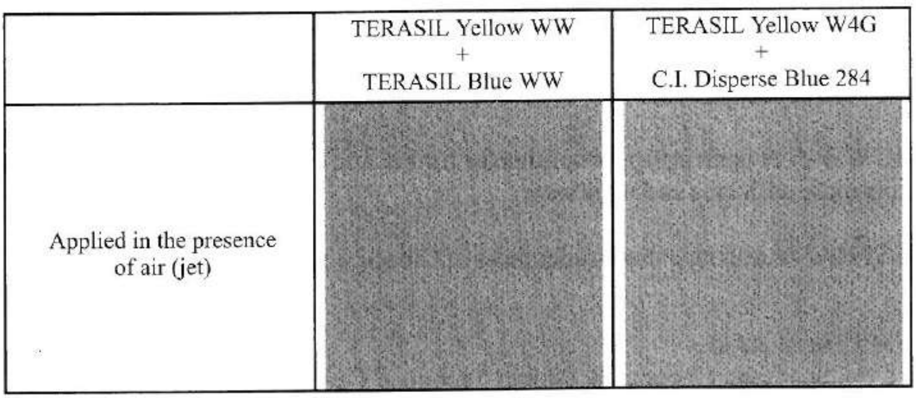
Sodium hydroxide	-	10 % (o.w.f)
Non-ionic detergent	-	0.5 gpl
M.L.Ratio	-	1:30
Temperature	-	5-10° C, 50° C, 70° C and 90° C
Time	-	1 hr.

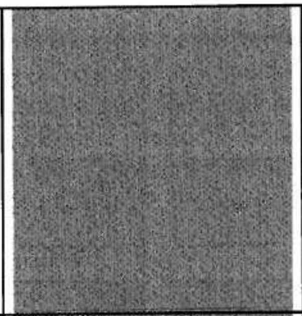
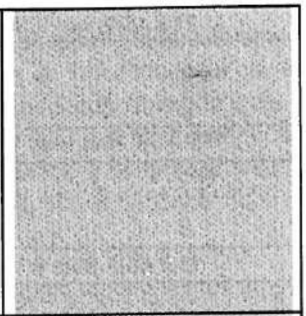
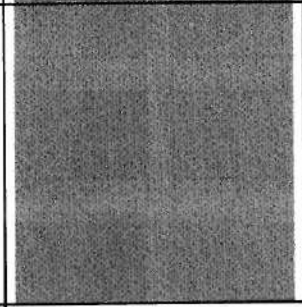
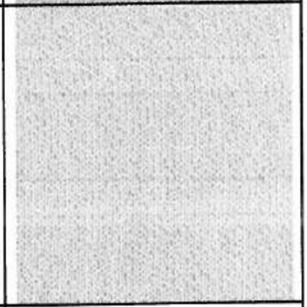
Treatment of polyester fibre with Sodium Hydroxide, Zinc Chloride, Benzoic Acid, Maleic anhydride for fixed duration with different concentrations to optimize chemical



The shades shown here are just some of those that can be produced with TERASIL WW dyes. Violets, oranges, royal blues and blue greens, for example, are also attainable and being developed. While the major reason for creating the new TERASIL WW range is its outstanding washing-off properties, these dyes also solve several other common drawbacks of older washfast ranges: for example, reproducibility problems caused by the limited resistance to reduction of the older washfast blue, navy, black and bluish red dyes are avoided, as are problems caused by the sensitivity to pH changes of most traditional washfast rubine and red dyes.

Fig. 6 Reduction sensitivity of washfast disperse dyes in a package dyeing machine.



Applied without air (package dyeing machine)		
Applied without air + 2% Reax 85 A (dispersing agents with reduction properties)		
Result	No shade change	Shade change
Dyeing reproducibility	Very good	Poor

CONCLUSION

A new, patent-pending and registered phthalimide azo chemistry has allowed the creation of a range of dyes that cover the full shade gamut and are distinguished by outstanding wash fastness on polyester and its blends, even under very severe washing conditions. This fastness level was so far only attainable with dibenzofuranone chemistry, and at a much higher coloristic cost. Furthermore, red was the only attainable shade. TERASIL WW dyes have created a new reference in wash fastness of polyester.

The new TERASIL WW range opens the way to development of highly attractive and worthwhile textiles in segments such as sportswear, underwear and other textiles worn next to the skin, as well as leisurewear.

TERASIL WW dyes open up opportunities for further and still more original effects, for outlets such as corporate uniforms and workwear.

Rolf Roos, *et al*
Ciba Specialty Chemicals, Global Technical Center, Dyes
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Table 3

	Areal Density (gm/m^2)	Fabric thickness (mm)	Air permeability (cubic $mt/m^2/min$)	Moisture regain (%)	Bending length (cm)	Flexural rigidity	Drape coeff.	Abrasion resistance		Tensile strength (kg)		Elongation (%)		Tearing strength (kg)		CRA	Colour strength (K/S)
								Warp	Weft	Warp	Weft	Warp	Weft	Warp	Weft		
Untreated	152	0.46	21.671	0.392	3.39	3009.45	1.699	0.85	0.715	89.6	80.6	23	20.3	6165.3	5610.6	275°	14.986
5-10°C	149	0.458	21.688	0.42	3.24	2589.67	1.658	0.893	0.748	88.7	79.6	21.5	20	5824	5489.6	274°	15.258
50° C	148.2	0.458	21.683	0.526	3.13	2334.76	1.647	0.816	0.751	86	79.3	19.8	19.6	5623	5440	274°	15.265
70° C	146	0.45	21.881	0.621	3.13	2334.76	1.531	0.910	0.793	74.3	73.3	18	17.6	5461.3	5120	255°	15.896
90° C	144.8	0.44	23.651	2.883	2.92	1895.64	0.931	0.983	0.821	68.6	64.5	15.3	15.2	5397	5077.3	240°	18.398

Table 9 Effect on fibre treated with different chemicals with optimum concentrations at temperature 90° C for 1 hr on fabric properties.

	Areal Density (gm/m^2)	Fabric thickness (mm)	Air permeability (cubic $mt/m^2/min$)	Moisture regain (%)	Bending length (cm)	Flexural rigidity	Drape coeff.	Abrasion resistance		Tensile strength (kg)		Elongation (%)		Tearing strength (kg)		CRA	Colour strength (K/S)
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Untreated	152	0.46	21.671	0.392	3.39	3009.45	1.699	0.85	0.715	89.6	80.6	23	20.3	6165.3	5610.6	275°	14.986
Zinc chloride	134	0.38	27.1715	3.45	2.51	2338.41	0.811	1.285	0.9	80.3	72.5	18	16	5397	5102	224.6°	18.859
Benzoic acid	133	0.38	25.5055	2.2	2.72	2419.52	0.912	0.98	0.76	72.5	70	18.5	18	5928	5317	236.5°	17.761
Maleic anhydride	130	0.38	24.8385	1.44	2.62	2591.21	0.728	2.110	1.19	80.5	73	15.5	14	5560	5056	235.2°	19.381
Sodium hydroxide	144	0.425	22.5045	3.3	2.58	2542.61	0.852	1.273	0.88	64.5	61	13.5	11	5223	4192	235.5°	18.388

Table 4 The properties of fabric prepared from the fibres treated with caustic 10% (o.w.f) at different temperatures assessed visually

	Pill Rating	Lustre Rating	Feel / Softness Rating
Untreated	3 (Moderate)	2 (Slight)	2 (Less)
5-10°C	3 (Moderate)	2 (Slight)	2 (Less)
50° C	3 (Moderate)	2 (Slight)	2 (Less)
70° C	3 (Moderate)	3 (Moderate)	3 (Moderate)
90° C	2-3 (Severe-Moderate)	3 (Moderate)	3 (Moderate)

From the table 4 it is clear that the Fabric feel and Lustre gets enhanced at treatment 90° C temperature as fabric becomes more aesthetic and softer. Found very slight improvement in pilling tendency of the fabric at ice, 50° C and 70° C temperature but pilling tendency is considerably reduced at 90° C temperature.

Effect on properties of fibre treated with different chemicals with concentrations 10 % 100 % at 90° C temperature for 1 hr. (Table 5 7)

It is observed that with the increase in concentration of different chemicals, the weight loss % and the moisture regain % of the fibre increases. In case of zinc chloride and sodium hydroxide treatment, found more % increase in moisture regain than other chemicals. With increase in concentration of the chemicals observed the reduction in fibre denier. Zinc chloride treatment shows little more reduction than other chemicals. The other properties of the fibre like fibre tenacity and fibre elongation % reduce as the chemical concentration increases. There is improvement in colour strength after treatment. The maximum increase in colour strength has seen in the treatment with Maliec Anhydride.

Effect of different chemical treatment with optimum concentration at 90° C temperature.

Effect on Fibre surface: - SEM photographs reflects that due to the treatment of the polyester fibre with different chemicals the itching of the surface takes place as observed surface pitting or surface damage. The treatment causes the surface reduction, i.e. wt loss and hence the fibre becomes finer as compared to the untreated fibre. Also it has been proved by denier reduction and weight loss from table 1, 5and 6. After treatment with different chemicals the fibre becomes porous. In case of treatment with Maliec Anhydride the maximum porosity is observed. After treatment of the fibre with different chemicals the fibre cross-section becomes circular to some extent as compared with untreated fibre.

FTIR Study -effect of different chemicals on molecular chain

The FTIR study indicates that in case of fibre treated with Zinc Chloride, overall transmission % is increased, as seen from all peaks at higher transmission % as compared with control. It shows peaks at 4000 4100 cm^{-1} region like untreated fibre but at higher transmission. This peak is related to C C, C H and C O bonds. The increase in transmission % at this region reflects that the chain becomes more flexible and also increase in mobility of it, which causes more dye diffusion hence more dye uptake and moisture regain %.

concentration.

Chemical concentration	-	10% to 100 % (o.w.f)
Non-ionic detergent	-	0.5 gpl
M.L.Ratio	-	1:30
Temperature	-	90° C, for 1hr

Treated samples were dyed 2% shade with Ciba disperse dye (Terasil Red W-4BS) by HTHP method, reduction cleared, washed and then spun into yarn, from those which shows better moisture regain, dye uptake, and optimum tenacity.

Preparation of yarn samples

as per normal spinning route and then prepared double yarn.

Preparation of fabric samples

Plain weave fabric samples were prepared on Cimco automatic loom. The fabric particulars are:

Weave	:	plain
Yarn count	:	$2/40^s$ (both for warp and weft)
Reed per inch	:	48
Pick per inch	:	44

Soaping/washing of fabric with non-ionic soap at 80 85° C for 30 minutes

TEST METHODS

Fibre tests

Fibre Length, Weight Loss %, Moisture Regain %, Fibre cross-section, FTIR, Breaking Strength, Elongation % (IS: 3675-1966) Fibre Denier (IS: 234-1973) Colour Strength (K/S)

Yarn Tests

Breaking Strength, Breaking Extension %

Fabric Tests

Fabric weight per square meter (IS: 1964-1970), Fabric Thickness (IS: 7702-1975), Air Permeability (IS: 11056-1984), Moisture Regain%, Bending Length, Flexural rigidity of (IS: 6490-1971), Drape Coefficient (IS: 8357-1977), Flex Abrasion Resistance (IS: 7016-1973), Tensile Strength, Elongation% (IS: 1969-1968), Tearing Strength (IS: 6489-1971), Crease Recovery Angle (IS: 4681-1968), Color Strength, Pilling tendency, Lustre, Feel or Softness.

RESULTS AND DISCUSSION

From table 1 it is seen that with increase in weight loss with increase in temperature. The moisture regain of the fibre increases with temperature and maximum at 90° C. In case of tenacity and elongation % of the fibre, it reduces at all treatment temperatures, but the maximum reduction has seen in case of treatment at 90° C. The denier reduction is also maximum at 90° C There is slight difference in fibre properties with treatment at ice (low temp) and 50° C temperature. The other property like colour strength of the fibre increases to great extent at 90° C temperature treatment.

Table 1 The various properties of polyester fibre treated with caustic at various temperatures 5-10C, 50C, 70C and 90C) and constant concentration (10%)

	Weight loss (%)	Moisture Regain (%)	Tenacity (gm/den)	Elongation (%)	Fibre Denier	Colour Strength (K/S)
Untreated	0	0.39	5.24	30	1.4	14.895
5-10°C	0.65	0.41	5.21	29	1.39	15.324
50°C	0.94	0.52	5.16	29	1.39	15.365
70°C	1.05	0.61	4.96	29	1.36	15.876
90°C	3.85	2.89	3.91	25	1.2	18.543

It is observed from the table 2 that the tenacity and elongation % of the yarn decreases after treatment and maximum reduction is observed in treatment at 90° C.

Table 2 The various properties of yarn prepared with polyester fibre treated with caustic 10% (o.w.f) at different temperatures for 1 hr

	Tenacity (gm/tex)	Elongation (%)
Untreated	34.24	13.37
5-10°C	31.24	12.95
50°C	28.29	12.35
70°C	27.88	11.75
90°C	25.12	11.51

In table 3, it is seen that the reduction in fabric weight and thickness is observed with increase in temperature and more reduction at 90° C temperature. The other properties like air permeability and moisture regain % are better at 90° C temperature. The fabric's bending length and fabric flexural rigidity i.e. stiffness gets reduced after treatment hence fabric drape coefficient also reduced at higher temperature. Abrasion resistance (flex) of the fabric gets improved after treatment. The tensile and tear strength decreses with rise in temperature (but in acceptable range). With increase in temperature fabric elongation % shows decreasing trend. After treatment the crease recovery angle of the fabric is reduced little extent at low and 50° C temperature and at large extent in treatment at 70° C and 90° C temperature. The dye yield is higher at 90° C.

thickness also gets reduced after treatment as compared to fabric prepared from untreated fibre. The fabric thickness of the fabrics prepared from the fibre treated with zinc chloride, benzoic acid and malice anhydride the thickness reduces considerably but in the case of sodium hydroxide treated fibre fabric there is slight change in thickness. This is due to the reason that during treatment with sodium hydroxide the swelling of the fibre takes place hence the fabric thickness is higher than the other treated fibre fabrics (seen from the SEM photograph of treated fibre). Air permeability is also a measure of comfort. The air permeability of the fabrics prepared from the fibres treated with different chemicals are higher as compared with the fabric prepared from the untreated fibres; because during treatment the fibres gets finer, hence it affect yarn and fabric properties. When fabric prepared from the treated fibres compared with fabric prepared from untreated fibres (same count, EPI and PPI) inter yarn spaces will be higher in fabric prepared from treated fibres hence air permeability gets increased. In case of the fabric prepared from the fibres treated with sodium hydroxide there is slight difference; this is due to the reason that the treatment with sodium hydroxide at higher temperature causes swelling of the fibre (seen in SEM photograph) hence no improvement in air permeability. On comparison with the fabrics prepared from the fibres treated with different chemicals at optimum concentration with the fabric prepared from the untreated fibres, the moisture regain of the fabric gets increased. This is due to the reason that during treatment with different chemicals at elevated temperature that is 90° C the hydrolysis and surface modification of the polymer takes place. Due to this hydrolysis the ester linkage gets ruptured hence there is availability of more no. of hydrophilic groups hence the moisture regain % of the fabric gets increased. The fabric prepared from the fibres treated with zinc chloride has maximum moisture regain as compared with fabrics prepared from the fibres treated with other chemicals. After the treatment with different chemicals the bending length reduces as the fibre becomes softer hence can bend easily under its own weight and the flexural rigidity is the measure of stiffness hence it also gets reduced. The fabric prepared from the fibre treated with zinc chloride shows minimum bending length and flexural rigidity as compared to other fabrics prepared from fibres treated with different chemicals. Higher the drape coefficient of the fabric stiffer is the fabric. The drape coefficient of the fabric gets reduced after the treatment with different chemicals. After the treatment the fibres becomes finer and softer hence the fabric prepared from these treated fibres able to drape smoothly and form pleats as the fabric becomes limper. It has been seen that the abrasion resistance of the fabric gets improved after the treatment with different chemicals. This is due to the reason that the fibres become finer and softer due to surface modification. Due to increase in surface area (seen from the SEM photographs) area of contact gets increased hence more time or more no. of cycles required to abrade this contact area hence abrasion resistance gets improved. The tensile strength of the fabric, which depends on the fibre as well as yarn properties. Treatment with different chemicals at 90° C shows that the tensile strength as well as the elongation % of the fabric gets reduced. The tearing strength of the fabric prepared from the fibres treated with different chemicals also gets reduced as compared to the fabric prepared from the untreated fibres. The crease recovery angle of the fabric prepared from the fibres treated with different chemicals also reduced as compared to the fabric prepared from the untreated fibres. It is observed that the zinc chloride treated fibre fabric shows minimum crease recovery angle as compare with other chemical treatment. The colour strength of the fabrics prepared from the fibres treated with different chemicals are higher than the fabric prepared from the untreated fibre because originally the structure of the polyester is very compact and crystalline and after treatment the porosity of the fibre gets increased as polymer chains becomes more flexible and hence it becomes easier for dye molecules to diffuse in the fibre structure. Hence the colour strength gets enhanced. The fabric prepared from the fibres treated with malice anhydride shows highest K/S because porosity is considerably more in this case.

Effect on Pilling tendency, Lustre and Handle (Table 10)

It is observed that treatment with zinc chloride reduces the pilling tendency, while other chemicals shows somewhat more pilling than untreated one. For luster visual assessment was done and the fabrics prepared from the fibres treated with different chemicals shows higher luster than the untreated fibres fabric. In the case of fabric prepared from the fibres treated with sodium hydroxide gives duller appearance as compared to the other fabrics prepared from the fibres treated with different chemicals. Zinc chloride treatment shows more Lusture than untreated fibre fabric. Other chemically treated fibre fabric shows somewhat better Lusture but less than zinc chloride treatment. Handle of the fabric is also visually assessed and the fabric prepared from the fibres treated with different chemicals becomes very much softer and appealing to handle due to surface modification as compared to the fabric prepared from the untreated fibres. Zinc chloride treatment shows better softness as compare to untreated and other chemical treatments.

CONCLUSIONS

Caustic treatment shows maximum weight loss, finer denier, loss in tenacity, and little loss in elongation with more increase in moisture regain and colour yield at 90° C than other temperatures. Also study of SEM and FTIR shows that, the caustic treatment causes chain scission at ester linkages and thus hydrolysis of it, resulting in loss of protruded polymer chains and availability of free -OH and -COOH groups. This results in increase in moisture regain and more diffusion of dye particles, causing increase in dye yield. Higher temperature of treatment 90° C on fibre and fabric from it shows lesser bending length, stiffness, drape coefficient, density, CRA (better than cotton), lowering of elongation, tenacity, tear strength (in acceptable range), increase in abrasion resistance, reduction in fabric thickness, increase in air permeability, increase in colour yield and better luster, feel etc are favorable properties for cotton like properties to improve comfort in wear for consumers.

Looking at the result of caustic treatment, 90° C temperature was selected for treating polyester fibres with different chemicals, as $ZnCl_2$, Benzoic acid and Maleic anhydride at 10 to 100% concentrations. From the result of fibre properties on denier, weight loss, moisture regain, tenacity, elongation, and colour strength etc, the concentration of different chemicals were selected for further yarn and fabric performance study, considering optimum values of fibre properties.

Fibes treated with Sodium Hydroxide the peaks at 1100 1300 cm^{-1} at higher transmission % are due to free carboxylic group and peak of 1400 wavelength region are of- OH groups and at higher transmission%. In this case no peak at 4100 cm^{-1} like control. -OH stretching and Ar H stretching at higher transmission % is seen (peaks at 3430 and 3000 cm^{-1}). The prominent peaks of OH and COOH groups indicates that treatment causes chain scission, thus hydrolysis of ester linkage. Also seen from earlier table on weight loss, denier reduction, tenacity reduction, elongation reduction and increase in moisture regain, dye yield etc.

Treatment with Benzoic Acid, the graph is almost same as of sodium hydroxide but at higher transmission % i.e the chains are more flexible. More CO stretching is seen in peaks at 1700 1750 cm^{-1}. Similar to sodium hydroxide, it causes hydrolysis of ester linkages causing free OH and COOH groups. Thus reduces surface fibre.

In case of fibres treated with Maliec Anhydride also shows similar behaviour like sodium hydroxide. Its transmission % is also similar to the sodium hydroxide.

Table 5 Effect on fibre treated with different chemicals with concentrations 10%-100% at 90° C for 1 hr on Weight Loss % and Moisture Regain %.

Concentration (o.w.f)	Weight Loss %				Moisture Regain %			
	Zinc Chloride	Benzoic Acid	Maleic Anhydride	Sodium Hydroxide	Zinc Chloride	Benzoic Acid	Maleic Anhydride	Sodium Hydroxide
10 %	0	0	1	3.72	0.6	0.55	0.6	2.89
20 %	0	1	1.8	3.98	0.9	0.8	0.8	2.91
30 %	0	1.8	2	4.3	1.6	1.45	1	2.91
40 %	0.6	2.9	3	4.9	2.5	1.75	1	3.1
50 %	0.8	4.4	3.5	5.6	2.9	1.98	1.3	3.2
60 %	2	5.3	4.8	6.1	3.1	2.01	1.39	3.32
70 %	4	6.4	5.1	6.8	3.5	2.11	1.44	3.54
80 %	4.9	7.6	5.95	7	3.8	2.18	1.64	4.1
90 %	6.4	8.6	6.5	7.5	3.85	2.19	2.39	4.3
100 %	10.4	9.02	6.8	8.6	3.91	2.21	2.51	4.4
					Untreated	0.39		

Table 6 Effect on fibre treated with different chemicals with concentrations 10%-100% at 90° C for 1 hr on Fibre denier and Tenacity.

Concentration (o.w.f)	Fibre Denier				Fibre Tenacity (gm/den)			
	Zinc Chloride	Benzoic Acid	Maleic Anhydride	Sodium Hydroxide	Zinc Chloride	Benzoic Acid	Maleic Anhydride	Sodium Hydroxide
10 %	1.33	1.4	1.4	1.2	4.55	4.51	4.767	3.98
20 %	1.258	1.4	1.4	1.18	3.95	4.31	4.691	3.91
30 %	1.258	1.32	1.4	1.18	3.43	4.26	4.622	3.78
40 %	1.16	1.25	1.33	1.12	3.27	4.16	4.577	3.72
50 %	1.16	1.23	1.23	1.08	2.99	3.99	3.411	3.65
60 %	1.1	1.23	1.23	1.08	2.82	3.9	3.238	3.61
70 %	0.95	1.23	1.23	1.02	2.73	2.62	3.13	3.41
80 %	0.95	1.08	1.058	1.02	2.62	2.48	3.088	3.28
90 %	0.88	1.08	1.058	1.02	2.21	2.41	2.651	3.1
100 %	0.88	1.02	1.058	1.02	2.04	2.31	2.314	2.85
	Untreated	1.4			Untreated	5.24		

Table 7 Effect on fibre treated with different chemicals with concentrations 10%-100% at 90° C for 1 hr on Fibre Elongation and Colour Strength.

Concentration (o.w.f)	Fibre Elongation %				Colour Strength (K/S)			
	Zinc Chloride	Benzoic Acid	Maleic Anhydride	Sodium Hydroxide	Zinc Chloride	Benzoic Acid	Maleic Anhydride	Sodium Hydroxide
10 %	27	27	25	25	15.025	15.552	16.097	18.026
20 %	27	26	25	25	15.0978	15.721	18.644	18.129
30 %	25	25	24.5	25	15.9399	16.197	19.563	18.414
40 %	25	23.5	23	23	15.9703	16.454	19.959	18.693
50 %	24	23	22	22.5	16.9855	16.745	20.136	19.765
60 %	22.5	21	22	22.5	17.214	18.097	20.536	20.765
70 %	22	21	21.5	22	18.2727	18.37	21.433	21.414
80 %	19	20	21	20	19.9855	19.037	21.666	21.857
90 %	18	16	20	20	20.8621	19.699	22.934	22.05
100 %	17	16	19	18	21.985	19.871	25.3	22.268
	Untreated	30			Untreated	14.895		

Effect on yarn properties

The yarn properties depend on the fibre properties. Due to treatment with different chemicals the yarn tenacity and elongation % of the yarn gets reduced as shown in table 8. It is observed that the reduction in tenacity and elongation % of the yarn prepared from the fibre treated with Zinc Chloride is minimum and maximum in the treatment with Benzoic acid.

Table 8 Effect of different chemicals on yarn prepared from fibre treated with optimum concentration at 90° C for 1 hr.

	Tenacity (gm/tex)	Elongation (%)
Untreated	34.247	13.37
$ZnCl_2$ (50%)	30.319	12.72
Benzoic Acid (70%)	23.182	11.88
Maleic Anhydride (60%)	26.546	12.01
Sodium Hydroxide (60%)	26.818	13.216

Table 10The various properties of fabric prepared from the fibres treated with different chemicals with optimum concentration at temperature 90° C for 1 hr. (assessed visually).

	Pill Rating	Lustre Rating	Feel / Softness Rating
Untreated	3 (Moderate)	2 (Slight)	2 (Less)
Zinc chloride (50%)	4 (Slight)	4 (Good)	4 (Good)
Benzoic acid (70%)	3 (Severe)	3 (Moderate)	4 (Good)
Maleic anhydride (60%)	2 (Severe)	3 (Moderate)	3 (Moderate)
Sodium hydroxide (60%)	2-3 (Severe-Moderate)	3 (Moderate)	3 (Moderate)

Effect on fabric properties (Table 9)

The fabric aerial density gets reduced after the treatment with different chemicals. The fabric prepared from the fibre treated with Maleic anhydride shows minimum weight. In the case of treatment with Sodium hydroxide it shows that there is slight change in weight. Fabric

Yarn properties indicate that, $ZnCl_2$ treatment on polyester fibres shows no much loss in tenacity and elongation %. Thus this yarn is suitable for better weaving performance than other chemicals treated fibre yarn.

Fabric prepared from optimum concentration of chemicals treatment on fibers, spun into yarn, the result on it shows lesser value of bending length, flexural rigidity, drape coeff., fabric thickness, fabric density, CRA (but better than cotton fabric), improvement in abrasion resistance, more air permeability than untreated fibre fabric. These are the suitable properties towards cotton like comfort in wearing polyester clothing for consumers. Treatment shows improvement in moisture regain of around 3-4% as compare to 0.4 % of normal polyester. Higher moisture regain % is the favorable condition for reducing static charge generation, resistance to oil, soil, dirt and dust etc in treated fabric than untreated one. Tensile and tear strength after treatment shows some drop in values, but they are very well, in acceptable range w.r.t durability of fabric. The color strength is also on positive side in treated fibre fabric. Thus compare to normal polyester, the amount of dye required to dye the required shade, can be saved.

While purchasing fabric for particular function/fashion wear etc irrespective of season (summer, winter, rainy season) wearer always look for good luster, soft feel, comfort, wash and wear and also durability and price. The treated fibre fabric shows better luster, softness, wash and wear and other properties (as mentioned above), which are the requirement of today's and tomorrows customers globally. Out of different chemicals treatment on polyester fibers, $ZnCl_2$ (50%) treatment shows better properties w.r.t all above properties expected by consumers in market. $ZnCl_2$ treated fabric are towards cotton like properties like softness, comfort, and good luster and durability like polyester.

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