Science and technology of man-made fibres: The Indian R&D scenario

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The research and development work relating to the science and technology of man-made fibres covers a very wide field which includes the manufacture of fibre-forming polymers, conversion of polymer to fibres, manufacture of yarns and fabrics and their chemical processing. The R&D work being done in India in these different areas is briefly reviewed in this paper with particular reference to the significant work done during the past ten years or so. Though every attempt has been made to include the major contributions made by different groups in the country, the account is by no means comprehensive. Finally, some areas have been identified, particularly the weak and emerging areas, in which there is a definite need to strengthen the R&D base.

Keywords: Fibre-forming polymers, Man-made fibres

1 Introduction

The manufacture of textile products based on man-made fibres involves a number of operations which require significant inputs from scientists, technologists and engineers. To begin with, the fibre-forming polymer is synthesized and then converted into a fibre, usually by extrusion of polymer melt or solution through narrow holes and subsequently by subjecting the extruded filament to some post-extrusion operations like drawing, heat-setting, etc. Yarn and fabric manufacture represent the next two steps. Finally, textile chemical processing ensures the necessary aesthetic and functional value addition to the product. During these different stages of production, the chemists, chemical engineers, fibre scientists and technologists, textile technologists, textile engineers, textile chemists, mechanical engineers, and electronic and instrument engineers are called upon to play various important roles. The manufacture of textiles and textile products is thus truly an interdisciplinary effort. Of late, microprocessors and computers are being extensively used for on-line controls and for fabric design and consequently the need for persons with appropriate computer science and engineering background is expected to grow.

The Indian tradition of making textile products from cotton, silk and other natural fibres goes back to the Indus Valley civilization. The organized textile mills were established in India during the nineteenth century. Limited research on some aspects of textiles, mainly cotton-based, was already being pursued in the pre-independence days in some universities and educational institutions (e.g. University of Bombay and the Victoria Jubilee Technical Institute, Bombay) and laboratories (e.g. Cotton Technological Research Laboratory, Bombay). After independence, the Government of India decided to provide technological assistance to the industry by setting up Textile Research Associations (TRAs), the first such association being established in Ahmedabad in 1947. The Government of India also decided to promote research in various areas by starting a chain of national laboratories, establishing the five Indian Institutes of Technology (IITs) and by providing more funds for university research. The Textile Department at IIT-Delhi started functioning in 1961. At present, a bulk of the R&D work relating to the science and technology of man-made fibres is being done in some educational institutes, research associations, national laboratories, petrochemical complexes and industrial units. Some of the significant contributions made by these organizations during the past decade are reviewed in this paper.

The abbreviations used for the various organizations are listed below (in the order in which they appear):

NCL National Chemical Laboratory, Pune
IITM Indian Institute of Technology, Madras
IPCL Indian Petrochemicals Corporation Ltd, Baroda
IITK Indian Institute of Technology, Kanpur
IITD Indian Institute of Technology, Delhi
cases with foreign collaboration. Work on indigenous development and evaluation of catalysts for petrochemical conversion processes is done principally at NCL, IITM and IPCL. In house R&D work on various aspects of raw material production is done by the manufacturers but a detailed consideration of this field is not intended to be covered in this article. The R&D work done in India on the other aspects of fibre manufacture will now be briefly described.

2.2 Production of Polymers

Significant contribution on the modelling of poly(ethylene terephthalate) (PET) reactors for direct continuous esterification, prepolymerization and polycondensation processes has been made by NCL. The variables influencing the side products in the transesterification reaction and molecular weight distribution of PET in homogeneous, continuous-flow-stirred tank reactors have been studied at IITK (Chemical Engineering Department).

The transesterification reactions of dimethyl terephthalate (DMT) with ethylene glycol (EG) using barium sulphate (BaSO₄) and titanates in conjunction with metal acetates were studied at IITD (Textile Technology Department). It was demonstrated that the catalytic activity of metal acetates is retarded by the addition of BaSO₄ in transesterification which is further impaired by pyrophosphate titanates. SPRC (J.K. Synthetics) has studied the kinetics of transesterification reactions and developed a mathematical model for the same.

Synthesis of aromatic-aliphatic copolyesters by different polycondensation processes (interfacial, low and high temperature, solution and melt condensation) has been reported by IITD.

EIL (1) has contributed to the upgrading of technology of PET polycondensation unit. EIL (2) has recently started manufacturing poly(butylene terephthalate) (PBT) from which filaments have been melt-extruded.

Work on acrylonitrile fibre-forming polymers has been done at IITD. Acrylonitrile has been copolymerized with a number of comonomers (hydroxyalkyl acrylate, acrylic acid and methacrylic acid) to yield fibre-forming polymers with higher hydroscopicity and improved dyeability. Haloalkyl acrylates have also been used as comonomers to produce flame-retardant acrylic fibres.

NCL is working on controlled synthesis of acrylic polymers and has contributed to the modelling and simulation of acrylonitrile plants.

In the area of high performance fibres, NAL has developed the polymer for making aramid fibres of ‘Kevlar’ type while at VSSC, carbosilanes, the precursor for SiC fibres, have been developed. Work on the production of carbon fibres from polyacrylonitrile precursor has been done at NPL and IPCL.

2 Fibre Manufacture

Fibre manufacture involves the following steps: (a) production of raw materials including monomers, (b) production of fibre-forming polymers, (c) conversion of the polymer to fibre, and (d) modification by physical (e.g. blending) and chemical (e.g. grafting) means.

2.1 Production of Raw Materials

The raw materials for fibre manufacture are produced in both public and private sectors, in most cases with foreign collaboration. Work on indigenous development and evaluation of catalysts for petrochemical conversion processes is done principally at NCL, IITM and IPCL. In house R&D work on various aspects of raw material production is done by the manufacturers but a detailed consideration of this field is not intended to be covered in this article. The R&D work done in India on the other aspects of fibre manufacture will now be briefly described.

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2.3 Production of Fibres

The fibre production process involves the conversion of the fibre-forming polymer to a fibrous shape mainly by extrusion through narrow holes using melt, wet or dry spinning techniques. The extruded filament is then subjected to post-spinning operations like drawing and heat-setting.

The extrusion or fibre spinning processes involve fluid flow and mass and heat transfer. NCL has made significant contribution to modelling and computer simulation of melt spinning of PET. Through sensitivity analysis they have identified the most important primary spinning variables which control fibre properties. IITD has also done a limited amount of work on computer simulation of melt-spinning of PET yarns using a variable force steady state model. The equipment for fibre production is mostly imported although some plants and machinery are being manufactured indigenously (e.g. by GIL, mainly for viscose rayon production).

With the help of miniature laboratory melt- and wet-spinning units and using rheometers, considerable significant work has been done at IITD on the various factors which affect the quality of the extruded (spun) yarns. Pilot plant facilities for melt-spinning of fibre-forming polymers have been set up at SASMIRA, BTRA, MANTRA and IITD. Laboratory-scale melt-spinning units have now been installed in a number of industrial R&D units. Standardization of variables in the production of nylon 6 and PET filaments has been undertaken at most of these units. The wet-spinning of acrylonitrile copolymers has been studied at IITD and SPRC. Low coagulation bath temperature and high draw gave fibres with better strength. The influence of spinning dope additives such as secondary cellulose acetate, polyvinyl pyrrolidone, glycerol and polyvinyl acetate on the structure and properties of acrylic fibres has also been studied at IITD. It was observed that acrylic fibres show higher dye uptake compared to the conventional fibres if secondary cellulose acetate is used as an additive.

The work on spin finishes has been done mainly at BTRA, IITD and ATIRA. At BTRA and IITD, spin finishes have a number of desirable characteristics in addition to lubricity, e.g. anti-static, antibacterial, hydrophobicity, etc., have been developed and evaluated. The role of individual components in the mixture and the substitution of imported material with indigenously produced materials has been undertaken by BTRA, ATIRA and IITD.

In the areas of drawing and heat-setting, a considerable amount of work has been done at IITD, UDCT, ATIRA, BTRA and MANTRA. The main emphasis is on (i) optimizing the drawing and heat-setting parameters, and (ii) correlating the changes in property with the changes in structure. IITD has studied both the aspects involving all fibre-forming systems. The studies in the other laboratories relate mainly to the second aspect.

At IITD, factorial design of experiments has been applied to nylon 6, polypropylene and fibres made from polymer blends to optimize the draw ratio and temperature of drawing. The other aspects of drawing include identification of the roles of stress, strain rate and temperature in the flow drawing of PET fibres; molecular chain scission in nylon 6 fibres on drawing; and stress-induced crystallization during drawing of PET fibres. The drawing characteristics of acrylic fibres with particular emphasis on differential shrinkage have also been studied.

Various aspects of heat-setting of fibres have been studied in different laboratories. MANTRA and ATIRA have studied the dye uptake in PET in relation to heat-setting parameters like temperature and tension. ATIRA has also studied the chemical etching of PET as a function of heat-setting parameters. At BTRA, the swelling of nylon 6 and its effect on their structure and properties have been investigated. Extensive studies have been made at IITD on structure-property relationships in heat-set PET yarns with emphasis on mechanical, optical, thermal and dye uptake properties and their dependence on structural and morphological characteristics like crystallinity, crystal size, crystal defects, crystal orientation, amorphous orientation, nature of coupling between the crystalline and amorphous regions, etc. The mechanical properties have been investigated in detail and include dynamic mechanical properties in tension and torsion, stress relaxation, creep, tensile load-elongation behaviour, and recovery from tensile deformation. The elastic, viscoelastic and plastic regions have all been studied. The optical properties include birefringence with particular reference to characterization of molecular, orientation in the amorphous phase by combining the birefringence data with the data obtained from X-ray diffraction and infrared spectrophotometry. Scanning and transmission electron microscopy of PET fibres have yielded useful structural information. The thermal properties studied include the glass-transition phenomenon and melting point, and the crystallization kinetics.

At UDCT, the morphological changes in drawn, aminolized, dyed and heat-set polyester have been studied. At the Department of Textiles of SNDT University, solvent-aided dyeing of PET fibre has been investigated.
2.4 Modification by Physical and Chemical Means

Considerable improvements in fibre properties can be obtained through physical blending of polymers. IITD has studied a number of blend systems, e.g. nylon 6/PET, PET/PBT, fibre-grade PP/high molecular weight PP, nylon 6/nylon 66 and blends of PBT/liquid crystalline polymers. PP/polystyrene blends have also been studied with the aim of enhancing the dye uptake of PP. Melt-blending of PET/nylon 6 and its mechanical, structural and dyeing behaviour have been investigated at MANTRA. Grafiting of vinyl monomers on fibres has been undertaken at UDCT, IITD, BTRA, ACCM, MANTRA and MSUB. At UDCT, a number of synthetic fibres such as polyester, polypropylene, nylon 6 and acrylics have been graft-copolymerized with polar hydrophobic vinyl monomers. The resulting fibres were dyeable with acid cationic dyes and had greater capacity for moisture intake and higher electrical conductivity.

The grafting of nylon 6 fibre with methyl methacrylate and acrylamide and of polypropylene fibre with methacrylic acid has been studied at IITD. Fibres from copolymers having different hydrophilic and other comonomers, e.g. copolysteres, acrylonitrile-hydroxyalkyl acrylate/acylic acid, have been developed at IITD with a view to improve hydrophilicity and dyeability. Experiments have been conducted at MANTRA to improve the dyeability of polyamides by graft copolymerization, crosslinking and end group modification of nylon 6 fibres.

3 Waste Recycling

Work on waste recycling has been successfully done in a number of laboratories with particular emphasis on nylon 6, PET and acrylic fibres. At BTRA, polyester and acrylic wastes have been depolymerized and modified for use as textile finishes and also as sizes, binders and adhesives. At IITD, the suitability of acrylic fibre waste as a substitute for alginate in reactive printing has been established. The potentiality of saponified acrylic fibre waste as a promising and more economical substitute of sodium alginate has also been established.

4 Yarn Manufacture

The use of rotor spinning for making yarns from PET staple fibre has been investigated at ATIRA. A comprehensive study of mechanical and physical properties of rotor-spun yarns for synthetic blends has been conducted at IITD. The differential response of some man-made fibres and their blends to rotor spinning has been studied at SITRA. NITRA has carried out a systematic study on the spinning of doubled yarn at ring frame and the causes of excessive end breaks have been identified. At BTRA, the factors which contribute to variability of count and strength in polyester blended yarns have been identified. At MSUB, work on development of core-spun yarns has been done. At VITI, optimization studies relating to core-spun yarns based on nylon 6 and polyester/cotton has been carried out. Detailed studies on nylon 6/viscose core-spun yarns have been carried out at TITB. SITRA has developed a core-spun sewing thread containing polyester filament as core and cotton as cover; it is claimed to be better in terms of both quality and performance during sewing.

At MANTRA, the effect of different twist levels on the physical properties of nylon 6, viscose and polyester yarns and of fabrics made from these filament yarns has been examined.

5 Texturing

The texturing of polyester yarns has been studied at a number of laboratories, e.g. ATIRA, BTRA, MANTRA, VITI and IITD. Texturing of viscose-polyester blends by simultaneous setting of components as well as solvent-aided texturing of PET, nylon 6 and rayons has been carried out at IITD. Simultaneous draw-texturing of polyester slit film for utilization in carpets and texturing of high denier polypropylene for knitsweats have been also carried out at IITD.

Considerable work on air-jet texturing of filament, spun and composite yarns has been carried out at IITD. The roles of raw material characteristics, particularly of inter-filament friction, and of process variables, on the structure and properties of air-jet textured yarns have been determined. A new method of measuring instability has been proposed. The mechanism of loop formation has also been studied.

At MANTRA, the texturing of nylon 6 and PET yarns and the influence of twist on textured yarns and fabric characteristics have been studied.

Various aspects of texturing of nylon 6 and PET multifilament yarns have been investigated at LML.

6 Fabric Manufacture

Sizing has come to be recognized as an important process in fabric manufacture because of its significant role in affecting the weaving performance. For sizing of man-made fibre-based fabrics, the conventional starch-based sizes are being replaced by newer formulations. ATIRA has developed a formulation based on hydroxyethyl starch, enabling cost reduction. ATIRA has also demonstrated that the use of maximum possible pressure on the sizing machines improves the weavability of polyester/cotton blended yarns in addition to saving on steam...
consumption. BTRA has developed an economical synthetic size from polymer waste with a view to replace polyvinyl alcohol. II TD has formulated sizes based on acrylates and modified starches for blended yarns. The sizing process has also received some attention. Work on cold sizing has been done at BTRA while work on high pressure squeezing has been reported from NITRA and II TD. MANTRA and BTRA have carried out some studies on the sizing of zero-twist polyester yarn.

A comparison of properties of fabrics made from rotor-spun yarns and conventional yarns, based on synthetic blends, has been attempted by II TD.

Considerable efforts are being made to develop the use of computers for fabric design. WRA, AAPP, ATIRA, BTRA and II TD have made some contributions in this area.

Nonwoven fabrics have assumed considerable importance more recently due to the widening of their application area, e.g. filter fabrics, geotextiles, etc. The major work in this field has been carried out at BTRA, where different types of coated, bonded and laminated nonwoven fabrics have been developed. Development work on the production of nonwoven fabrics based on viscose and nylon using needle punching has also been carried out at BTRA. Geotextile materials based on polypropylene and polyethylene are also being studied with particular emphasis on their use as canal liner. Thermal bonding and chemical bonding techniques along with needle punching have been used to produce nonwoven fabrics from polyester, acrylic and polypropylene fibres. Several experimental products like geotextiles, industrial filters and wadding blankets have been produced.

7 Textile Chemical Processing

7.1 Desizing

The newer sizes applied to synthetic yarns are relatively easy to remove. At UDCT, detailed studies have been made on the removal of starch and tamarind kernel powder (TKP)-based sizes.

7.2 Scouring

Scouring of fabrics made from synthetic fibres involves treatment with soap and soda at boil and only a limited effort has been made in further development of this process. UDCT and ATIRA have suggested formulations for scouring (and also bleaching) at room temperature with the aim of saving energy and cost. Work at UDCT has led to the development of a suitable scale to express the scouring efficiency.

7.3 Bleaching

Bleaching of textile materials made from man-made fibres has been studied in a number of laboratories. Various formulations have been studied at UDCT, II TD, ATIRA and BTRA for single-stage desizing, scouring and bleaching and also for cold bleaching. Studies on fluorescent brightening agents and their estimation have been made by UDCT. Auxiliaries have been formulated at BTRA which reduce the consumption of optical brighteners for polyester fabrics and also for polyester/cotton blended fabrics. ATIRA has found that the use of activated hydrogen peroxide results in rapid bleaching operation. The use of solar energy for fabric preparatory processes is being actively pursued at II TD.

Various formulations for the removal of stain have been developed by ATIRA, BTRA and UDCT.

7.4 Mercerization

For mercerization of polyester-cotton blended fabrics, the standard process for mercerization of cotton fabrics has to be slightly modified. Limited work in this area has been done at UDCT where the effect of additives in the mercerization bath on the efficiency of mercerization has been studied. At BTRA, a hot mercerization technique for polyester-cellulose blends has been developed.

7.5 Dyeing

Various aspects of the dyeing of synthetic fibres and their blends have been studied in a number of laboratories. These investigations have been made with the following principal aims: Achievement of single-stage desizing, scouring and bleaching and also for cold bleaching. Studies on fluorescent brightening agents and their estimation have been made by UDCT. Auxiliaries have been formulated at BTRA which reduce the consumption of optical brighteners for polyester fabrics and also for polyester/cotton blended fabrics. ATIRA has found that the use of activated hydrogen peroxide results in rapid bleaching operation. The use of solar energy for fabric preparatory processes is being actively pursued at II TD.

Various formulations for the removal of stain have been developed by ATIRA, BTRA and UDCT.
Studies relating to disperse and cationic dyeing of differentially-dyeable polyesters have been carried out at UDCT and MANTRA. Instrumental methods of colour matching and computer colour matching have been pursued at ATIRA, UDCT, BTRA and WRA for different dye classes and substrates. These techniques have been accepted by many leading process houses.

7.6 Printing
Printing could be considered as localized dyeing and the various laboratories engaged in R&D work on dyeing are also active in the area of printing of fabrics based on synthetic fibres. Some of the work done by them is reviewed here.

The effects of retarders and sequestering agents on dischargeability and yellowing with stannous chloride have been studied at UDCT, MANTRA and ATIRA. The fixation of disperse dyes on polyester and of other dyes on respective component fibres in blends during printing has received attention in the work carried out at UDCT, BTRA and ATIRA. Detailed studies on foam printing have been made at BTRA and ATIRA. Synthetic thickeners have been developed by UDCT, ATIRA and IITD to replace kerosene partially or fully in pigment printing. R&D work at IITD, UDCT, ATIRA and BTRA has established that modified guar gums can be used for printing of synthetic fabrics.

UDCT has developed a process for the application of pigmented emulsions of polymerized oils in textile printing. They have also studied the alkali sensitivity of disperse dyes in printing and the mechanism of dye release from the thickener film and its transfer to polyester fabric. Rheological studies on synthetic thickeners and various natural thickeners have also been made at UDCT.

At IITD, extensive studies have been made on the flow properties of starch-grafted copolymers as a function of pH, temperature of printing paste and electrolytes. IITD has also studied thickeners obtained from acrylic fibre wastes which were found to be economical but the performance of the prints was not always of the highest order.

BTRA has reported that tamarind kernel powder could be used as a more economical substitute for guar gum for printing of synthetic fabrics. BTRA has also studied various binders used for pigment printing on khadi.

ATIRA has developed a process for micro-encapsulation of dyes for producing a 'speckled print' effect. It has also developed a low-temperature curing catalyst which results in energy saving in pigment printing.

MANTRA has studied the printing of cationic dyeable polyester.

In the field of transfer printing, IITD, UDCT and BTRA have studied various aspects of sublimation transfer printing of synthetics as well as their blends with natural fibres. A commercially feasible method has been developed at IITD for transfer printing of polyester/cotton blends.

7.7 Finishing
Various aspects of finishing of fabrics made from synthetic fibres and their blends with natural fibres are being studied in a number of laboratories.

Weight reduction is an important finishing treatment for polyester fabric and has been studied in a number of laboratories including those at UDCT, BTRA and ATIRA. Detailed studies in this area have been conducted at UDCT taking different types of polyester fibres (easy dyeable and cationic dyeable) with different textures and crimp effects.

Foam finishing techniques have been standardized at ATIRA and BTRA.

Resin finishing is known to improve crease recovery but is generally accompanied by loss in tensile strength. ATIRA has demonstrated that if mild scouring conditions are maintained followed by the use of a low-temperature curing catalyst during resin finishing, strength deterioration can be minimized. Efficient catalysts have been developed by IITD for rapid curing in easy care finishing of polyester cellulose blends; it has been reported that simultaneous setting and resin finishing can be achieved using suitable crosslinking agent and catalyst.

Attempts have been made at UDCT, ATIRA, BTRA, IITD and SASMIRA to develop speciality finishes for water-proofing, flame-proofing, anti-static treatment and soil-release. Various finish formulations have been developed at IITD for polypropylene blankets and carpets and for acrylic fabrics.

8 Fibre- and Fabric-Reinforced Composites
The manufacture of composites, in which fibres or fabrics form the reinforcing phase, is a very fast growing area which has considerable potential in India. Some work on composites based on glass fibres and fabrics as reinforcement has been done at IITD and IITM while composites based on carbon fibres have been developed and studied at IITB. IPCL has also done development work on composites.

9 Instrumentation
Significant R&D work on developing instruments for the textile industry is being done at a number of places with the Textile Research Associations being
in the forefront. AAPP has also been quite active in this area. Some industrial houses have developed and are marketing a number of instruments.

10 Weak and Emerging Areas

There are a number of weak and emerging areas in which there is urgent need to enhance the R&D efforts. These include: reactor design for industrial equipment for manufacture of fibre-forming polymers; process design; development of precision engineering components and tools, metering pumps, spinnerettes and other spares for fibre production plants, and high speed spinning equipment; technology for dry-jet wet spinning and gel spinning; technology for development of speciality fibres and microfilaments; development and production of auxiliaries like antioxidants, anti-static agents, delustering agents, sizes and finishes; development of industrial fabrics including nonwoven fabrics; and use of computers for process control, on-line monitoring and fabric design.

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Note

A considerable amount of material for this article was collected from the following sources:

(i) Annual reports and other reports of Textile Research Associations, NCL, IITD and UDCT.

(ii) Papers published in various journals during the past ten years.

(iii) Report of the High Power Committee appointed by the Ministry of Textiles, Govt. of India, New Delhi, to review the working of Textile Research Associations (September 1989).

(iv) Final report prepared by Shri Ram Institute for Industrial Research, Delhi, on 'Techno-Economic Study of Synthetic Fibre Industry in India' sponsored by the Department of Scientific & Industrial Research, Ministry of Science & Technology, Govt. of India, New Delhi (October 1989).