Part II
Improving functionality of polyesters and polyamides

7
Specialty fibers from polyesters and polyamides

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7.1   Introduction

Out of the many polymers developed for synthetic fibers, only a few dominate the commercial market. Polyesters and polyamides are the most widely used textile fibers. Polypropylene fiber has a major presence in nonwovens and to some extent in carpets and rugs. These fibers are commercially produced in large capacity plants, available in sufficient quantities, and are priced relatively low. Overall, these industries appear to have smooth sailing ahead since demand is increasing due to the growing population, but there are issues such as overcapacity, increased competition, and narrowing profit margin. Some manufacturers are diversifying into specialty markets by creating a series of new products using the same machinery with minor modifications in the process or equipment. These specialty fibers are focused on high value products that are new and improved over current materials, in both existing and new applications.

Typically, commodity fibers have a circular cross-section. Other cross-sections such as hollow, trilobal, hexagonal, etc., are considered specialty fibers. This modification can be accomplished by installing spinnerets with the desired capillary configuration. Due to the change in the cross-section, they exhibit amazing properties. For example, hollow fibers have better insulation properties, and trilobal cross-section fibers have a sparkle. Similarly, there has been growing interest in the specialty fiber markets comprised of two polymers, known as bicomponent fibers. These bicomponent fibers are produced by melting two polymers of differing structure separately, bringing the constituent polymer melts together in the die capillary, and fusing them into the forming fiber. A bicomponent fiber with a PET core and an HDPE sheath is a very popular binder fiber in nonwoven production.

Commodity fibers are generally made from homopolymers. The specialty fibers are produced from the polymer through chemical modification. Modifiers are added at some stage of the polymerization process or
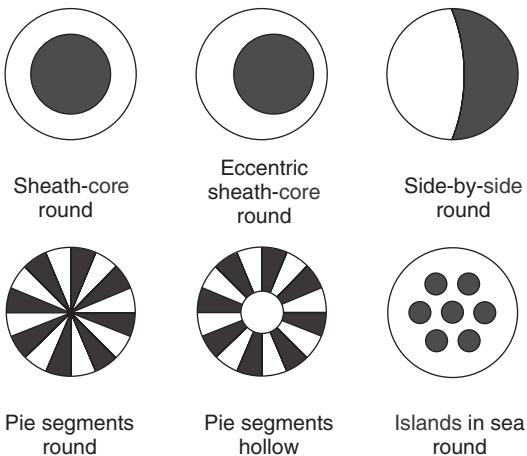
during polymer extrusion. Cationic dye-able polyesters, flame retardant polyesters, and biodegradable polyesters are examples of modified polymers.

Specialty fibers are born out of research and development efforts tailored to meet the application-specific needs. This is accomplished if the modifications are easy to implement, and modifiers are easily available, exhibit better performance attributes, cover wider needs, and the products are readily available to the user. Special considerations at the design and manufacturing stages of these specialty fibers are discussed in this chapter.

7.2   Production, properties and applications of physically modified fibers

7.2.1   Bicomponent fibers

Bicomponent fibers are comprised of two different polymers of differing structure melted separately and spun together into one fiber. The constituent polymer melts are brought together in the die capillary and fused into the forming fiber. The design of the spinneret-pack assembly plays an important role in the quality and cost aspects of this product. This involves additional capital cost for the second polymer melt system and the special spinneret packs. Furthermore, cleaning, maintaining the parts, and inspection of these spinnerets are more expensive compared to monocomponent spinning. More common types of bicomponent fibers[1] are (as shown in Figure 7.1): sheath-core, side-by-side, segment pie, and islands-in-the-sea

Sheath-core round

Eccentric sheath-core round

Side-by-side round

Pie segments round

Pie segments hollow

Islands in sea round

7.1 Bicomponent fiber cross-sections.

bicomponent fibers. Advanced Fiber Engineering[2] has developed nearly 400 specialty capillary designs for such applications. Advanced fabrication techniques are used in achieving capillaries to produce fibers with various shapes providing high shape factor or high specific surface. This increased surface area is useful in trapping dirt, with hollow cores of desired shape to enhance permeability and acoustic behavior, and perfect geometry to impart desired feel, stiffness, and light effects (luster, sparkle etc.).

Sheath and core

The largest commercial use of bicomponent fibers of the sheath-core type is for self-bonding binder fibers consisting of low melting temperature sheaths and higher melting temperature cores. Common sheath/core combinations in such applications include PE/PET, Co-PET/PET, and PP/PET. These fibers are usually blended with commodity fibers in the desired proportion to produce nonwoven webs by carding, air laying or any other suitable technique. Such webs can be through-air bonded or calendered. The sheath provides the fusing point while the core preserves the integrity of the fibers in the nonwoven. In these cases, the core always consists of a higher melting polymer than the sheath. The products containing these binder fibers can be processed at temperatures ranging between the melting temperatures of the sheath and the core. A major advantage is that it creates a nonwoven free of chemical bonding agents and is widely used in through-air thermal bonding of natural fiber or staple fiber webs.

A second type of sheath-core is filled fibers consisting of a core product produced from either cheaper material, or expensive materials (such as metal, dye) to impart desired special properties as well as esthetics to the final product. Improved conductivity is achieved by having a metal or carbon core in the bicomponent fibers. A third type of sheath-core is filled fibers consisting of a sheath product produced from expensive material (such as heat or chemical resistant polymers) to impart desired special properties as well as to keep the product economical.

In both the second and third type of bicomponent fibers discussed above, the desired property or functionality is on the surface and the additive does not have to be in the whole bulk of the fiber. Since specialty additives are generally quite expensive, reducing the amount of needed additives leads to considerable cost savings.
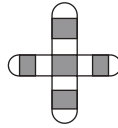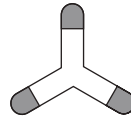
Side-by-side

Side-by-side products are typically used as self-bulking fibers. Self-bulking is imparted by two polymers having different shrinkage properties. These self-bulking fibers have a higher bulk and have found use in staple fiberfill

Hollow pie   Ribbon   Segmented   Tipped
                          cross   trilobal

7.2 Various types of segmented fiber.

applications. Recently, they have been used in textured upholstery fila-
ments. This technology is gaining popularity due to its higher processing
speeds, and reduced cost. Sometimes the side-by-side bicomponent fibers
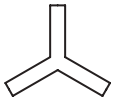can be split into two fibers as well.

Segmented

Various types of segmented fiber cross-sections are shown in Figure 7.2.
Segmented-pie fibers are made of segments of two polymers as in a 'pie-
diagram'. The fibers with an 8-segmented pie or 16-segmented pie are the
popular ones used as precursors for microfibers. Splitting apart the com-
ponents of segmented-pie fibers produces microfibers that are finer than
conventional microfibers, but these are mixtures of two polymeric micro-
fibers. A hollow segmented-pie structure assists in splitting apart and gene-
rates finer microfibers. The cross-section that is most readily splittable[3] into
microfibers is a segmented ribbon. But they are difficult to card because
of the anisotropic bending moment and very fine denier. To improve per-
formance in the card, fibers with multiple lobes such as the cross and the
trilobal cross-sections were tried. Generally, it is preferable to produce
carded webs and then split the fibers.

Islands-in-the-sea

Islands-in-the-sea type bicomponent fibers are used to produce nanofibers
using a novel method. Often the islands are made of PET, and the sea
comprised of a special type of polyester that is hot water soluble or caustic
soluble. Hydroentangling is one of the techniques used to break the islands
apart from the sea. The separated islands form nanofibers, which are
typically coarser than the electro-spun nanofibers.

7.2.2   Non-circular cross-section and profile fibers

Generic thermoplastic polymeric fibers have a solid circular cross-section.
In the melt spinning process, the cross-sectional geometry of such fibers

Type	Spinneret hole design	Fiber cross section
Hollow fiber		
Ribbon fiber		
Trilobal fiber		
Hexagonal fiber		

7.3 Specialty fiber cross-sections.

depends on the spinneret holes, which are circular for conventional fibers. Moreover the fibers emerging from the circular holes of the spinneret are subjected to the heat transfer phenomenon that takes place in the quench chamber. The shrinkage forces act in the radial direction and lead to the circular cross-sectional geometry of the fiber. Other desired cross-sections such as hollow, trilobal, hexagonal, etc. (as shown in Figure 7.3) can be accomplished by using the desired spinneret-hole configuration. Non-circular capillary fabrication requires sophisticated electron beam milling and electro-discharge machinery. This involves additional capital cost for procurement. Furthermore cleaning, maintaining the profile and inspection of these spinnerets are more expensive. Hence non-circular cross-sectional fibers are produced when the value-added properties offset the additional cost involved.

   Hollow fibers are lightweight and have excellent insulative properties. They are used as filler fibers in pillows and cushioned furniture. Trilobal cross-section fibers have reflective surfaces, giving rise to a sparkly appearance; hence they are often used in luxury apparel. Trilobal fibers provide rigidity and resilience, and the reflecting surfaces are efficient at scattering light to hide any dirt. For these reasons, trilobal fibers are often used in carpets. Similarly a ribbon cross section has flat surfaces for the reflection of light, so its appearance is also highly sparkly. Ribbon fibers pose much

7.4 '4DG' fiber cross-section with deep grooves.

7.5 Cross sections with high shape factor.

difficulty in carding. Multi-segmented ribbon bicomponent fibers are good for producing micro fibers by splitting after carding.

4DG® Fiber with their deep groove capillary surfaces was first developed by Eastman Chemical Co., Kingsport, TN, and then donated to the Clemson University Research Foundation. The 4DG cross-section is shown in Figure 7.4 and other cross-sections with high shape factors are shown in Figure 7.5. The deep grooves or channels along the longitudinal axis of the fiber are unique features of the fiber that can help move fluid spontaneously, trap particles, provide large surface areas, and bulk cover per denier per filament. Usually, either hydrophilic or hydrophobic surface finish is applied to the fibers, based on the application. 4DG fibers can accumulate more dust particles if they are used in filters or if they carry more carbon particles placed in the grooves for odor absorbency on the right. 4DG is one among the various thermal insulation materials used in a Mars space suit. Presently Fiber Innovation Technology, Inc.[3] Johnson City, TN manufactures the 4DG fiber. Coolmax fabrics produced by Invista[4] consist of fibers with uniquely engineered micro-channel cross-sections with a denier gradient, but the channels are not deep as in 4DG. The fabrics move moisture away from the body, thus keeping the skin cool, dry, and comfortable. Potential applications are: perspiration shields, sweat bands for athletes, mascara brushes, condensate collectors, mops and brushes, socks, cosmetic applicators, oil absorbers, wipes, filter media, and wound care materials.

7.2.3   Monofilaments

Monofilaments[5] are continuous filaments with high tenacity used in engineered fabrics or yarn. In order to achieve this, a high viscosity of the raw material is essential along with a higher level of purity. The conventional process produces PET polymer of intrinsic viscosity of about 0.65 dl/g maximum. An additional processing step, the solid-state polymerization (SSP) process, is required to upgrade the intrinsic viscosity from 0.6 to 1.0. Polycondensation is carried out by fluidizing the polyester chips in hot nitrogen gas at ~210°C (about 10 to 20°C below the softening point of polyester). SSP is a very slow process, and it needs 20 to 30 hours of residence time in the reaction column, as the rate depends on removal of volatiles by diffusion through the polymer into the fluidizing gas (nitrogen). Depending on the application, newer polymers such as ultra-high molecular weight polyethylene (UHMWPE), polyethylene naphthalate (PEN), etc. are used to produce monofilaments with profiled cross-sections or chemically treated surfaces.

7.2.4   Microfibers and nanofibers

Fibers with a denier of less than one are known as micro-denier or microfibers. Generally, microfibers are produced by the melt blowing process. Such microfibers have diameters in the range of 1 to 15 microns. The melt blowing process is simple in machinery and construction, but a lot of variables are involved in determining the fiber diameter, fiber diameter distribution and the web structure. The process produces webs as individual fibers cannot be collected or handled, and these self bonded webs are used as filters for various applications. Almost any thermoplastic polymer can be melt blown to produce a microfiber nonwoven web.

Further, fine fibers with a diameter of less than 100 nm are called nanofibers, and usually are produced by an electrostatic spinning process, which is discussed in the following chapters. Recently, a lot of research has been done in the area of electrospinning as this process allows the production of nanofiber webs from several polymers, and the nanofiber structure has tremendous surface area. This makes these webs suitable for absorption, filtration and other related applications.

7.3   Production, properties and applications of chemically modified fibers

Specialty fibers can be produced from chemically modified polymers as well as copolymers. Modifiers are the chemicals added at some stage of the

Table 7.1 Chemical modification of fibers

Modification	Chemical used
Low pilling polyester fiber	Pentaerithritol, glycerol
Cationic dyeable polyester fiber	5-sulfoisophthalic acid – Na salt
Cationic dyeable nylon fiber	Disodium 3,5-disulfobenzoic acid
Flame retardant polyester fiber	Organo-phosphorus compound
Antistatic polyester – bicomponent	Carbon or metal core / suffused thru surface
Antistatic nylon fiber	Monoethyl ether of polyethylene glycol
Low melt polyester fiber	Adipic acid or isophthalic acid
Caustic soluble polyester polymer	Polyethylene glycol and 5-sulfoisophthalic acid
Heat and chemical resistant polyester	Naphthalene and butylene compounds

polymer process or during extrusion. Table 7.1 contains the list of modifying chemicals, specifically chosen for the desired application.

7.3.1 Low pilling fibers

Pilling is the formation of little knots of fiber on the surface of a fabric, as a result of wear, contact, and abrasion. As a fabric rubs against another surface, fiber is pulled away from the yarn, protrudes, and entangles to form a knot on the surface of the fabric. This occurs in all fabrics and gives them a fuzzy appearance, more often in staple fiber based fabrics. On natural fabrics, when pills form they break and fall off. Since synthetic fibers are stronger, the pills formed do not break away, and hence they are more noticeable on synthetic fabrics than on natural fiber based fabrics. Chemical modification to achieve low pill polyester fibers involves the introduction of a weak spot in a strong polymeric chain. Generally, the modifier, glycerol or pentaerithritol, is added in the bulk polymerization. Other methods make use of microfibers or a low-pill finish, which looks excellent after wearing and laundering.

7.3.2 Improved dyeable fibers

Unlike natural fibers, polyester fibers are difficult to dye because of their chemical structure. Their dye pick up is very low, in spite of the use of high pressures and high temperatures. Modifiers like polyethylene glycols contribute slight openness in the polymer chain structure that eases dyeability. But in order to obtain darker and brighter shades comparable to silk, it is necessary to introduce dye reactive spots in the polymer chain.

The popularly used reactive modifiers contain compounds based on 5-sulfo-isophthalic acid; they are incorporated into the chain during the synthesis of polyester. As these modifiers are costly, the cationic dyeable polyester fibers and fabrics are expensive.

Nylon 6 has good acid dyeability. The dye pick up is due to the large number of amino acid ($-NH_2$) end groups in the polymer chain. Regular textile grade fibers have about 60 equivalent amino acid end groups. By controlling the quantity of amine stabilizers in the process, amino acid end groups could be brought up or down to alter the level of dye pick up. Generally, when amino acid end groups are above 100 equivalents, nylon is ultra-deep dyeable and when amino acid end groups drop below 15 equivalents, it dyes in light shades. Sometimes, in order to impart basic dyeability, anionic sulfonate ($-SO_3$) groups are introduced into the nylon chain.

7.3.3   Flame-retardant fibers

In order to obtain flame-retardant (FR) properties, about 3 to 5 wt. % phosphorus compounds are inserted into the polyester macromolecules. Kosa[6] produces an FR polyester fiber with the trade name Avora® using a proprietary organic phosphorus compound which is incorporated into the polyester polymer during polycondensation. Avora fabrics are used extensively in the hospitality industry, the healthcare industry, and public areas. Flame resistance is built into the fiber chemistry, such that the protection does not wash out, age out, and meets flammability standards. Due to the presence of the FR compound, the melting point is marginally lower than regular polyester. However, the compound makes it difficult for combustion to take place as the fiber shrinks away from flames, chars, reduces melting drips from occurring, and prevents further burning by self-extinguishing. Combustion products are similar to generic polyester comprising of oxides of carbon and water vapor, as well as small quantities of aldehydes and ketones. Recent innovations include compounding with aluminum oxides, nanoclays and nanosilicates to impart flame retardancy. The use of halides is banned due to environmental and health hazards. Polyamides, however, have proved difficult to render durable flame retardancy by incorporation of additives because of their melt reactivities. Other non-polyester FR fibers in the market include Basofil, Nomex, Kanecaron, and Visil.

7.3.4   Antistatic and conductive fibers

Antistatic consists of a conductive core or layer along the fiber length made of conductive carbon or metal. Nega-stat[7] bicomponent antistatic fibers

consist of a tribal shaped conductive carbon core and a polyester sheath. Resistat[8] conductive fibers are produced by a carbon suffusion process that saturates the outer skin of the nylon fiber with electrically conductive carbon particles. The carbon practically becomes part of the structure of the fiber, which retains the strength and flexibility of nylon while maintaining excellent conductivity. A block copolymer containing polyether segments and a polyetherester also exhibits antistatic properties. Blending with polyether makes nylon fibers hydrophilic, and they absorb more moisture, which imparts an antistatic property. Antistatic fibers containing 5–15% conductive materials are blended with non-conductive fibers in stripe patterns to provide effective static dissipation for the life of the product. Antistatic fibers neutralize surface charges by induction and dissipate the charge by conduction when grounded or when ungrounded by air ionization, known as Corona discharge. Applications include industrial bags, brushes, conveyor belts, filters, carpets, and protective garments.

7.3.5   Biodegradable fibers

Polyester in its generic form, polyethylene terephthalate (PET), is not biodegradable. There are chemical modifications available to imbibe biodegradability. Biodegradable fibers are designed such that at the end of their useful life, they can be sent for composting, where they can decompose in an environmentally friendly way, which promotes the growth of plants, earthworms and microbes in the composting soil. Eastar[9] is a thermoplastic and biodegradable binder fiber produced by Eastman Chemical Company. Eastar is co-polyester with melting point ~120°C. Eastar is easily bondable with cellulosics, and the finished product is completely biodegradable. Biomax[10] from Dupont is another biodegradable polyester fiber. Biomax is modified hydro-biodegradable polyester with a melting point of 200°C. Proprietary monomers are incorporated into this polymer, creating sites that are susceptible to cleavage by moisture into smaller molecules, which are then consumed by naturally occurring microorganisms and converted to carbon dioxide, water and biomass.

Polylactic acid (PLA)[11] from Dow-Cargill is a biodegradable polymer that is produced from cornstarch. PLA fiber has a melting temperature of 175°C and tensile properties comparable to that of polyester fibers. PLA, as a melt spinnable fiber from a vegetable source, has many of the advantages of both synthetic and natural fibers. In addition to being produced from a renewable raw material, it is biodegradable. However, PLA has poor abrasion resistance and bonding behavior when compared to conventional binders. Other biodegradable fibers are Ecoflex[12] from BASF and polyhydroxybutyrate-valerate (PHBV) from Metabolix.[13]

7.3.6   Low melt binder fibers

The melting point of the most commonly used polyester fiber, polyethylene terephthalate, is about 260°C, but it can be reduced through the incorporation of modifiers such as isophthalates, adipates, etc. Polyester with a melting point of ~245°C is a commodity polymer used in making polyester bottles for soft drinks. These modifiers are added during polymerization, and they cause some distortion and defects in the polymer chain leading to a drop in the melting point accompanied by a minor drop in the glass transition temperature. A drop of about 2 to 3°C in the melting point is obtained by a percentage addition of the isophthalate group in the polymer chain. Adipates cause very large drops in the melting point, two to three times that of isophthalates. Low melt fibers (with melting point of 110°C or 130°C) are usually blended with commodity fibers in the desired proportion and then thermal bonded into webs. Generally bicomponent fibers with a low melt polyester sheath and a conventional polyester core are popular in the market. The binder fiber fuses with other non-melting fibers in the vicinity at the contact point, and it preserves the integrity of the nonwoven. A major advantage is that it creates a fabric free of chemical bonding agents.

7.3.7   Caustic soluble fibers

The presence of the right proportion of long chain polyethylene glycols, sodium salts of sulfo-isophthalate compounds, etc. helps to imbibe caustic solubility in polyesters. A novel method of producing microfibers involves the dissolution of the sea in the 'islands-in-sea bicomponent fibers' wherein the islands are made of conventional PET, and the sea is made of caustic-soluble polyester.

7.3.8   Chemical and heat resistant fibers

Increased chemical and heat resistance is achieved by the introduction of bulky groups such as naphthalenes and butylenes in the polymer chain. One-hundred percent polyethylene naphthalate (PEN) has high glass transition temperature (125°C) compared to PET (68°C). Moreover PEN fibers start to shrink significantly at 190°C [150°C for PET]. Naphthalene molecules in the polymer chain impart higher tensile strength, UV stability, and high temperature resistance. They also have better barrier properties and are more resistant to hydrolysis in alkaline or very hot aqueous conditions. PEN fibers are used in sail cloths, and hot liquid filtration media. However, they are more expensive and have a lower flex life. To lower the

cost PEN blends[14] with PET have been tried. Polyphenylene sulfide (PPS)[15] and Halar[16] fibers are also used in such applications.

7.3.9   Water absorptive fiber

Water absorptive fibers[17] are used in sportswear to absorb and take away the sweat. Hollow polyester fibers have porous walls with pore size 10 to 30 nm in diameter and absorb water by a capillary phenomenon. The pores run through the surface into the hollow core. QUUP is water absorbing nylon fiber that contains proprietary nitrogen based polymer that has water absorb/release properties. HYGRA is another nylon skin-core fiber where core is made up of hydrophilic polymer.

7.3.10 Deodorant fiber

Deodorant fiber has the ability to absorb volatile compounds from the atmosphere, generally tested with formaldehyde. Daiwabo has developed polymer with proprietary amine compounds in the chain that absorbs formaldehyde as well as other vapors such as ammonia, acetic acid, and cigarette smoke.

7.3.11 Smart fibers

Smart[18] fibers for different applications are made from chosen polymers for specific applications, and they are different from generic polyesters or polyamides. Smart fibers are generally tailored for specific applications such as artificial muscles, intelligent biomedical garments, adaptive textile structures, thermo-regulated snow clothing, etc.

7.3.12 Micro grooved fibers

Micro grooves on fibers are obtained by blending micron sized additives while producing the fibers and then taking away the additives at the finishing stage, mostly by dissolution. While drawing, stretching, and setting the blended additives do stretch and leave groves along the fiber at the final stage.

7.3.13 Lotus leaf effect

Water and soil repellency in fibers is achieved by imparting ultra hydrophobic nature through lotus leaf effect.[19] Basically the fibers need to have low surface energy and have the extended degree of surface roughness. A combination of a surface attached polymer layer and nanoparticles provide

the desired results. A polystyrene layer is grafted onto polyester fiber. Further the topography and the resulting roughness of the surface is tuned, by changing the size and shape of the nanoparticles. Ultimately the water contact angle close to 130° is found to provide adequate hydrophobic properties.

7.3.14 Surface treated fiber – dull luster

In order to control luster, generally titanium dioxide is added at the polycondensation stage of the manufacture. Fiber surface treatment[20] by chemical means is a method to modify the characteristics of smooth fibers as it imparts dull luster as well as new textile properties such as fluffiness and warmth retention. Generally caustic chemicals are employed in the treatment.

7.3.15 Fibers with controlled shrinkage

Heat setting is the operation carried out to control the residual shrinkage in the fiber. Generally fiber is subjected to heat under tension by passing over oil heated drums. In this process as the crystallinity increases the shrinkage reduces. Fibers with low shrinkage (less than 1%) are used in sewing threads. Other approaches such as adding nucleating agents to enhance crystallization during fiber formation are studied extensively but their commercialization is limited.

7.3.16 Other specialty fibers

Compounding with nanoclays or nanosilicates enhances mechanical properties such as heat distortion temperature and tensile strength as well as the flame retardancy of the product. Nanoparticles have a very high aspect ratio and hence possess a high surface to volume ratio. In order to obtain the advantages, it is essential to have proper surface wetting, dispersion and exfoliation of the nanoparticles. The polymer-layered silicate (PLS)[21] exhibited increased modulus and strength, decreased gas permeability, and decreased flammability. While nanoclay adds muscle to plastics, carbon nanotubes impart electrical and thermal conductivity. Single wall and multiwall carbon nanotubes[22] are relatively new, and their commercial potential has been limited by their high prices.

7.4   Design and process control aspects

Modifiers and additives cause some changes in specialty polymer behaviors with respect to heat transfer, glass transition, melting, crystallization, and

orientation of the molecular chains compared to the conventional poly-mers, and hence call for some minor adjustments in the processing condi-tions. Basics of fiber technology[23] and advanced fiber spinning[24] involve process as well as heat transfer parameters. Conventional polyester fibers are made from polymers having an intrinsic viscosity (IV) of 0.600 to 0.650. For specialty fibers, more or less the same melt viscosity is required, but chemical modification can offset the relation between melt viscosity and IV. In certain specialty fibers, the process-loss in viscosity during melting and spinning is more than normal (~0.020). In such cases, an appropriate adjustment is to go for slightly higher viscosity polymer granules. Specialty fibers with modified fiber cross-sections are obtained by the controlled solidification of the melt streams emerging out of the spinneret capillaries. The final cross-section depends upon the machine and process variables.

Operating variables are online variables that can be changed while the machine is being operated. These variables include throughput and tem-peratures of the polymer and quench air, collector or winder speed. The quench air is adjusted towards a lower velocity profile for finer fibers. There are a few variables at the drawing and heat setting stages. All of these affect the final properties of the fiber. Off-line variables are fixed before starting the spinning process, and can only be changed with downtime or when the machine is not in operation. These variables include spinnerets (capillary design) and quench air profile setting hardware.

In the case of conventional fibers, the spinneret holes or capillaries are in the diameter range of 0.1 to 0.5 mm, with a length to diameter (L/D) ratio of 2 to 5. Finer filaments are produced with the smaller diameter capillaries, at lower melt speeds and at slightly higher melt viscosity. Melt extrusion velocity is in the range of 5 to 75 m/min (for conventional fibers 5 to 50 m/min).

For specialty cross-sections, calculations are carried out based on the same principles used in conventional fibers with a slightly more complex formula derived for the specific geometry. In the case of hollow fibers, in order to get a fiber cross-sectional inner diameter to outer diameter ratio (d/D) of 0.3, spinneret capillaries d/D of about 0.6 are required. Generally, the capillary bridge width is about 20% of the outer diameter of the capillary. In the case of ribbon fibers, in order to get a fiber cross-sectional length to width ratio (L/w) of 4, it is required to have spinneret capillaries L/w of about 12. For trilobal fibers, the preferred cross-sectional leg length to width ratio of the spinneret capillaries (L/w) is 3.

7.5   Future trends

With the continuing pressure for better quality, assured performance at lower prices is the primary goal of a manufacturer of commodity products.

Research interests often go for niche products in relation to the specific performance properties. This encourages the search for new materials and innovative approaches to satisfy the short-term and long-term goals. Composites containing polymers, fibers, nonwovens, films, and foams are growing and demonstrating their potential to replace conventional materials. The coming years will see dramatic changes in the level of their acceptance and the diversity of their use, as engineers gain control over the necessary design skills, and wider adoption makes them more cost effective. Moreover, with increased thrust for using raw materials from renewable resources, biodegradability of the product is demanding a shift from conventional synthetic fibers that are too stable and do not degrade in the municipal waste.

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Property enhancement through blending

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8.1   Introduction

The increase in the production of synthetic fibres in the past few decades
has been phenomenal. This can be broadly attributed to two factors. First,
lack of availability of natural fibres and second, controllable and superior
properties of synthetic fibres like polyester and polyamide. These synthetic
fibres have many superior properties such as uniformity in length and
strength, freedom from foreign impurities and the flexibility in regard to
the desired staple length and denier. In addition, some highly popular
fibres like polyester impart higher tenacity, greater abrasion resistance and
better crease resistance to the fabrics. However, these fibres have some
negative attributes like proneness to static generation, low moisture regain,
etc. Therefore, for most of the end uses especially the apparels, the common
practice in the textile industry has been to use blended yarns instead of
100% single fibre yarns. Blending of fibres is also carried out in technical
uses as well to enhance the properties of the final product or to reduce the
cost of the product.

The aspect of blending of polyester and polyamide fibres with other
fibres can be considered in two different ways: one, for apparel applications
and two for production of speciality products like core spun yarns and
nonwovens and other related products. For apparel end uses, blending is
normally carried out in the fibre stage, i.e, blending of different fibres in
the staple form and spinning them into yarn. In the case of core spun yarns,
blending of one component in continuous filament form and the other in
the staple fibre form are combined at the yarn spinning stage. In nonwoven
processes, blending of different types of staple fibres or already formed
yarns is carried out in one of the nonwoven processes like needle punching
or stitch bonding to obtain a blended product. The majority of the polyester
blends go into making the apparels where yarn uniformity in terms of mass
variation and dyeability are critical. Hence, in this chapter the principles
and methods involved in blending of staple fibres, particularly with

polyester and nylon, are discussed first. Second, significant amounts of polyester and polyamides are combined with other fibres to make industrial clothing, conveyor belting, tentage, elastic yarns and sewing threads through core-spinning technology. Hence, in the second section of the chapter, the technology of core spinning and other technical textile products made through nonwoven processes are discussed.

8.2   Staple fibre blending

The blends normally consist of two (binary blend) or three different fibres (tertiary blend). Such blending of two or more dissimilar fibres offers an effective means of projecting the positive attributes or aspect of each of the constituent fibres. Blending, however, needs to be carried out in such a way that the fibres in a blended yarn are thoroughly dispersed and intermingled. Any deficiency in proper blending of fibres results not only in poor yarn properties but also fabric defects like fabric streakiness when dyed.

All fibres, whether natural or manmade, are quite in-homogeneous in respect of their characteristics. Blending, therefore, is a must to bring the desired homogeneity in their characteristics even in a 100% single fibre stock. Blending of dissimilar fibres is undertaken to achieve some other important objectives too and is quite common in the industry.[1]

In the case of polyester and polyamide fibres, blending is performed mainly in order to[2]

- Give the required characteristics to the product (e.g. blending of polyester fibres with natural fibres produces the desire easy-care character).
- Hold on raw material cost (blending in of relatively cheap raw material).
- Influence favourably the behaviour of the material during processing (use of segmented fibres having alternate segments of polyester and nylon).

The major objectives of blending are improvement in functional properties, improved process performance, better economy and improved aesthetics. One of the primary reasons for blending is to improve the functional properties of the fabrics such as higher tensile strength, uniformity, better appearance, increased wear life, crease resistance, crease recovery, dimensional stability, elasticity and comfort. A 100% single fibre yarn cannot possibly impart all of these desirable properties to the fabric. Take the case of polyester–viscose, a very popular blend. Fabrics from 100% viscose rayon suffer from low tensile and tear strength, poor crease resistance and recovery and low abrasion resistance. However, addition of polyester can

overcome these deficiencies because it has an excellent dimensional stability, crease retention, crease recovery, quick drying, increased abrasion resistance, higher tensile and tear strength. However, 100% polyester fabrics are also not desirable as they are prone to static accumulation, hole melting and pilling. They are moisture resistant (hydrophobic), difficult and expensive to dye and have a poor hand. Like polyester and viscose, each fibre has its own positive and negative attributes. These negative attributes of polyester and viscose can be reasonably neutralized by adding a certain percentage of each fibre. For example, the addition of viscose imparts to the polyester fabric a reduced static propensity and a marked protection against pilling. This also results in increased fabric absorbency and wear comfort. The other gains accruing from such a blend are the increased washability, increased affinity for dyestuffs and chemicals used in finishing.

Some fibres like polyester at times are quite troublesome to process in 100% form especially at the card. Addition of fibres like cotton or viscose rayon in the previous process has been seen to facilitate the smooth carding of such fibres. The blending of synthetic fibres which are longer and finer than cotton influences the spinnability as well as the productivity. Addition of a certain proportion of long fibres favourably influences the drafting characteristics of short staple fibres by acting as carrier fibres. The addition of fine fibres to a blend increases the number of fibres in the cross-section of a given count of yarn which leads to extension of the spinning limit. The longer fibres in the blend, in the same way, make it possible to spin finer counts. In ring spinning, such blending of longer and finer fibres gives substantial increase in production through a reduction in the required twist level, lower end breakage rate and higher spindle speeds. Such advantages obtained at the spinning stage seem to extend to a large extent to every post-spinning operation up to weaving or knitting.

Fabrics with a variety of colour mixture or shades can be produced by blending differently dyed fibres at the blowroom, drawframe or roving stage. Use of various fibres with different length, denier, colour and surface characteristics are employed to obtain unique fabric surface by exploiting the varying drafting and migratory behaviours of the fibres. Such effects are used to enhance the aesthetic appeal of a fabric.

Aesthetics of the fabric and garment are acquiring greater influence on the purchase pattern. The important aspects are fashion, texture, drape and lustre. All these attributes can be manipulated through selection of right type of fibre characteristics and specifications. The aesthetics of a fabric can also be developed by selecting specific blend components and their proportions. These parameters can be exploited to impart increased bulk, an attractive raised finish or a pleasing total variation to the fabric.

50/50   45/55   52/48
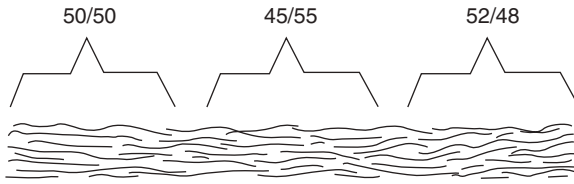
8.1 Unevenness of the blend in the longitudinal direction.
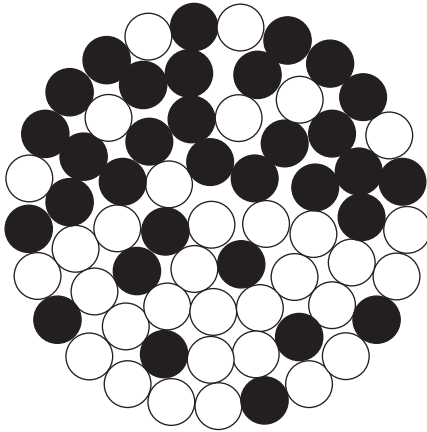
8.2 Unevenness of the blend in the transverse direction.

8.3   Evaluation of the blend

The evenness of the blend must always be assessed in two directions: the longitudinal direction and the transverse direction.[2] Where there is unevenness in the longitudinal direction, successive yarn portions exhibit different percentage distributions of the individual components (Figure 8.1). These can lead to stripiness.

Where there is unevenness in the transverse direction, the fibres are poorly distributed in the yarn section (Figure 8.2). This irregularity leads to an uneven appearance of the finished product.

The determination of the evenness of a blend, e.g. of synthetic and natural fibres, is costly and not simple. One component is usually dissolved out or coloured differently.

8.3.1   Indices of blending

For optimum exploitation and reasonable prediction of yarn and fabric properties from the properties of the constituent fibres, it is essential to

achieve a homogeneous or an intimate blend. Ideally, the blend should be a perfect blend in which every fibre property like length, denier and tenacity, etc. is found in the same proportion within every unit cross-section of the yarn. However such a blend can never be achieved in practice. The best one can achieve, is the one in which the constituent fibres of the blend are randomly distributed throughout the cross-section along the length of the yarn. This random distribution is seen to be close to a Poisson distribution. Generally, it is easier to obtain satisfactory results in this regard in a 50/50 blend than in an 80/20 blend. One of the important factors in achieving an intimate blend is to achieve the smallest fibre aggregates to the extent possible at the earliest stage of spinning. The blend homogeneity can be expressed either as the Degree of Mixing or the Index of Blend Irregularity.

Degree of mixing

This is a statistical parameter, which estimates the inherent intimacy of a blend. DeBarr and Walker[3] made a series of yarns from a blend of black and white fibres and examined their cross-sections for the number of groups of fibres. They assumed that the fibre distribution in yarn sections would become random as the number of doublings approached ∞. If g^∞ is the number of groups of white fibres, one can write:

$$g^\infty = np\,(1 - p)$$

where n is the number of fibres in the average cross-section of the yarn and p is the average proportion of white fibres in the blend.

In practice, the number of groups of white fibres is less than this since the number of doublings in use never achieves perfect randomization. If g represents the actual number of groups of white fibres, the degree of mixing (γ) is given as,

$$\gamma = g / g^\infty$$

A value of 1 for γ shows a thorough random distribution of fibres. A value of less than 1 means less than random mixing and a value of more than 1 means that the mixing is better than random. As this value increases, the blend approaches a perfect blend. In practice, the value of γ is less than 1 as the number of doublings increases. The finer yarns, therefore, require fewer doublings to achieve random distribution.

Index of blend irregularity (IBI)

This is another statistical measure used to assess the degree of randomness of fibre distribution. This index was developed by Coplan and Klein[4] for

variation in the blend proportion against the theoretical value for random mixing. The IBI can be calculated from the following expression,

$$IBI = \sqrt{\frac{1}{M} \sum \frac{(T_i p - W_i)^2}{T_i p q}}$$

where

T_i is the total number of fibres in a given cross-section,
W_i is the number of fibres of component W at the cross section,
p is the average fraction of component W for all cross-sections,
q is equal to $(1 - p)$ and
M is the number of cross-sections examined.

Obviously, this index is primarily a chi-square test. It is a normalized standard deviation. A value of zero would mean perfect blending and would indicate random blending. Values greater than 1 indicate less homogeneity than what complete randomness would give. This index can also be used to calculate the fibre cluster size. An index of 1.3 has the physical meaning that the blend suffers from causative factors that increase the homogeneity by 30% over what can be expected from a purely random process operating on single-fibre elements. By considering fibres to be in clusters, replacing Ti by Ti/C, where C is cluster size (number of fibres in the cluster), and substituting 1 for *IBI*, an estimate of cluster size can be obtained. Experiments on wool/nylon yarns spun on the woollen system suggested a cluster size of 2–4 fibres. Coplan and Bloch[5] expanded on the longitudinal variation method and developed two other methods of evaluation namely, radial distribution and rotational distribution of fibres.

Radial distribution[5]

This describes the fibre motion across the cross-sections of the yarn. To estimate this, the yarn cross-section is divided into, usually four, concentric circles of either equal area or thickness. Figure 8.3 shows circles of equal
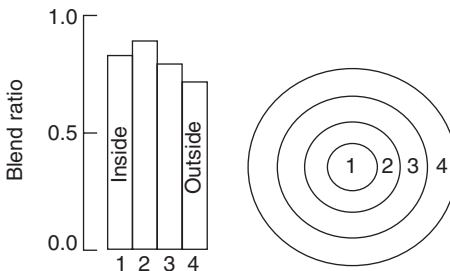
8.3 Radial distribution of fibres.
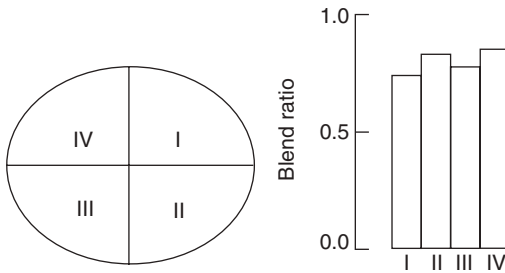
8.4 Rotational distribution of fibres.

thickness along with the blend ratio plotted in the form of a bar diagram. Ideally, the blend ratio should be the same in all four zones from inside to outside.

Rotational distribution[5]

For estimating the variation in the rotational distribution, the yarn cross-section is divided into four to six segments. The blend ratio is calculated and plotted as bar diagram as shown in Figure 8.4. Ideally the ratio should be the same for all the segments.

8.4   Migration

The segregation of components in a blend yarn is known as migration. A comprehensive understanding of this aspect of fibre behaviour is essential for the proper selection of fibres for a blend. The migratory behaviour of fibres in yarns arises from differences in tensions developed during twisting of fibres into yarn. The fibres twisting around a long path on the yarn surface would develop a high tension while fibres following a shorter straight path would be under lower tension. The tension differences would cause an interchange of position between the high and low tension fibres and thus lead to migration. It is known that, in a blend yarn the fibres having higher modulus tend to occupy the inner zones of the yarn cross-section and those fibres having lower modulus, the outer zone.

Cassie[6] postulated that for any spun yarn, the tendency for fibres to coil up and pack closely when twisted, depends on the parameter, $(1/\eta - 2/E)$, where η is the modulus of torsional rigidity of a fibre and E is its bending modulus. The greater the positive value of this parameter, the closer is the packing. Therefore, in a binary blend the component with a greater value of $(1/\eta - 2/E)$ will pack more tightly and hence tend to occupy the core of the yarns. Obviously, the component with the lower value of $(1/\eta - 2/E)$

will be displaced to the surface. In general, longer, finer and higher modulus fibres tend to migrate to the core of the yarn.

The dyed fibres and non-crimped fibres also tend to migrate to the core of the yarn. Therefore, in a blend yarn having dyed and undyed fibres or crimped and uncrimped fibres, the undyed and crimped fibres will predominate on the surface of the yarn. Fibre migration has significant influence on the performance and functional properties of yarns and fabrics. The migration is essential for producing a strong yarn by providing interlocking between different fibre layers of the yarn cross-section. A yarn with ideal helical geometry will not have such interlocking between these radial layers and there will be nothing to stop the fibres on the surface peeling off so that the whole yarn can be easily rubbed away.

In a binary blend if the stronger component migrates preferably to the core, the resultant blend yarn will have a higher tenacity. The fabric properties which are affected by migration include the pilling tendency, the soiling, the handle or feel, the drape and the abrasion resistance of the fabric. The defects like soiling and pilling can be contained by judiciously choosing the fibre properties of the blend components so as to put them at desired locations in the yarn cross-section. The extent to which this objective is achieved can be evaluated by determining the migration index.[1]

8.4.1   Migration index

The migration index of a blend can be calculated by using Hamilton's method.[7] This index is based on the calculation of certain first moments of the blend component about the centre of the yarn cross-section and relates the moment FM_a corresponding to the actual distribution, to the moments FM_u, FM_i and FM_o corresponding to three hypothetical distributions viz., uniform distribution, and those which would result from maximum inward and outward migrations, respectively. This is illustrated in Figure 8.5.

$FM_o - FM_u$ represents maximum possible outward migration.

For a polyester-cotton blend the expressions used for the calculation of this index are,

$$\text{Migration index for polyester} = \{(FM_a - FM_u)/(FM_u - FM_i)\} \times 100$$

$$\text{Migration index for cotton} = \{(FM_a - FM_u)/(FM_o - FM_u)\} \times 100$$

The above expressions are based on the fact that the polyester is going to migrate to the core and the cotton towards the surface. The two indices
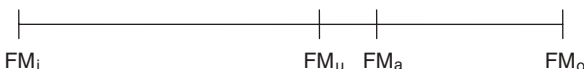
8.5 FMa-FM$_u$ represents actual outward migration.

will be seen to be equal but have opposite signs, i.e., if one is positive, the other will be negative. A negative value for a component indicates that it has preferentially inward migration whereas a positive value indicates outward migration.

8.5   De-blending

The spinner aims to distribute the different fibres evenly in the yarn. For this purpose he must first produce a good blend at some stage of the process, and second be able to maintain the blend up to the stage of binding into the yarn. As is well known, meeting the first of these requirements is not always easy; sometimes the second is harder still. Fibres of different length, different surface structure, crimp, etc., also behave differently during movements as individuals. A 'de-blending' effect can very often arise.[2]

During rolling of fibres in hoppers (bale openers, hopper feeders), migration of the components occurs where the fibres have different structures (e.g. cotton and synthetic fibres). A similar effect is found during drawing in drafting arrangements. Fibres with large differences in length or surface form (smooth/rough, dyed/undyed, etc.) do not exhibit the same cohesive contact with each other. When a drafting force is applied, they move differently – this leads to clumping of fibres into clusters and finally to de-blending. Pneumatic transport can also cause de-blending.

8.6   Selection of blend constituents

The choice of blend constituents needs careful consideration both in terms of the fibre type and their proportion in the blend so as to bring out their positive attributes and to suppress the negative ones. One has to further decide the specifications of these fibres, keeping in mind the end use requirements. For example, one may have to choose between low tenacity and high tenacity polyester, round cross-section or trilobal polyester.

8.6.1   Type of fibre

The major objective of blending two or more fibres is to produce a yarn or fabric with improved functional properties, which a single fibre just cannot achieve. Take the case of some popular blends like polyester-cotton or polyester-viscose, which are normally used, for apparels like shirting and suiting. If the fabric is made from 100% polyester it will have excellent crease resistance, durability, and wash and wear due to the hydrophobic nature of the polyester fibre.

Addition of a hydrophilic fibre like cotton or viscose rayon may render it more comfortable to wear because of their higher thermal conductivity and better absorption of perspiration. The body heat and perspiration are thus easily passed on to the outside air resulting in wear comfort. Such a blend fabric, therefore, overcomes the clammy feel of the 100% synthetic-fibre fabric. The fabric would also save the user from the pricking sensation due to lower bending rigidity of the cellulosic fibres and thus give it a softer feel.

The choice between cotton and viscose rayon for blending with polyester is primarily dependent on the end product. For a fuller look in lightweight fabrics, such as shirting, cotton is preferred. Even for heavier sorts such as working clothes and dyed uniform fabrics, cotton may be preferred to viscose so as to avoid a differential shade at the worn out portions. The viscose rayon fibre due to its lower abrasion wears out much faster than cotton, thus giving prominence to shade of polyester fibres which is generally somewhat different from that of viscose fibres. The blend with viscose would, however, give superior results to cotton in terms of yarn evenness, appearance, freedom from trash particles and contaminants. This blend is, therefore, preferred for medium and heavy constructions, such as suiting, where impeccable appearance is important. Similarly, blending of shrinkable and non-shrinkable polyester or other type of fibres is carried out to produce hi-bulk yarns.

The blends of two fibres, called binary blends, account for the major portion of the blended yarns produced. However, to a limited extent, the tertiary blends (blend of three types of fibres) are also produced. One such blend is the polyester-cotton-polynosic. Such blends are normally used for reasons of economy, styling and special surface effect in the fabrics. The objective of exploiting the positive attributes of each of the fibres is relegated to a secondary place in such tertiary blends. More often than not, such blends are produced for commercial exploitation by carrying the name of the most desirable but costly fibre though it may be present only in a small proportion. The tertiary blends can also be used for production of fabrics having multi-coloured effects during piece dyeing. This, however, demands a great skill on the part of the dyer and a thorough knowledge of the reactivity of one group of dues with another.

8.6.2 Compatibility of fibre blends

For trouble-free processing and optimum utilization of the positive attributes of the blend constituents, it is imperative to consider their compatibility in terms of their properties such as length, denier, breaking elongation, etc.

Length and denier

The two most important fibre properties, which need to be matched for satisfactory processing of blends, are the staple length and the fineness of the fibres. As a general rule, these two fibre properties should be nearly the same for all the constituents unless deviations are desired for producing some special effects. For blending of polyester with combed cotton of, say 34 mm, the denier of cotton component, generally in the range of 1.3 to 1.5 (3.6 to 4.2 μg/inch), is matched with 1.2 to 1.5 denier of polyester. Similarly in a viscose-cotton blend the viscose rayon of 1.5 denier and 29–32 mm length is generally used to match cotton of 1.5 denier (4.2 μg/inch) and 28 mm length.

The denier difference, on the other hand, seems to be detrimental to yarn quality as the migratory behaviour during twisting in yarn formation prevents intimate blending of fibre during twisting; the coarser fibres going to the surface and the finer to core. Excessive difference in the denier of the blend fibres, say 1.5 denier viscose and 3.0 denier polyester, has been seen to produce very weak yarns. It is difficult to lay down any firm tolerance limits for the difference in length and denier of the blend fibres. In general, it can be stated that if the differences in the length and fineness are high, the process performance and the yarn quality are expected to be poor.

Extensibility

The elongation compatibility of the constituent fibres is the most important fibre property in respect of achieving the maximum strength from a blend. In a blend, the fibre with a lower breaking elongation will break when the other fibre component is sharing only a part of its breaking load. After the breaking of the less extensible fibres, the full load is transferred to the more extensible component, as the less extensible fibres can no longer share any load. This extent of inequality in sharing of tensile load is determined by the load elongation curves of the two fibres.

Dyeing properties

In case the blend yarn or fabric is to be dyed subsequently, due consideration should also be given to the dyeing properties of the individual fibre components.

Tensile specifications of fibres

Having decided the type of blend fibres and their physical specifications, the next step involves careful consideration of the specific tensile
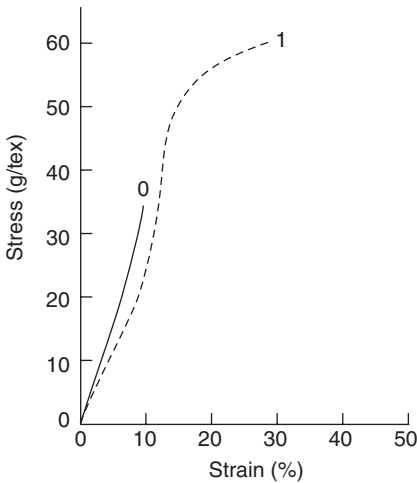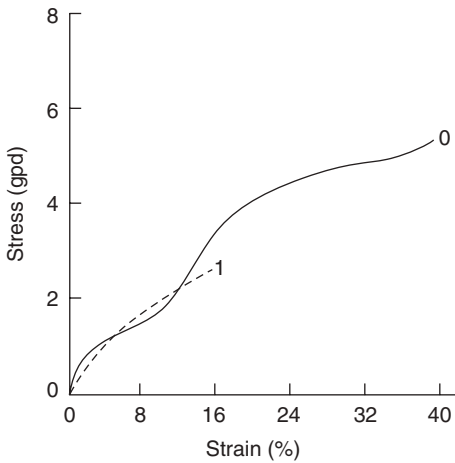
8.6 Stress–strain diagram of cotton and polyester fibres. 0: cotton, 1: polyester.

properties of the fibres in relation to the end product. For instance, the choice may have to be made between low-, medium-, and high-tenacity polyester fibres for blending with a variety of cottons. In case the desired end result is maximum tenacity, it will be desirable that in addition to the fibre length and the fineness, their stress–strain diagrams are also matched for an effective fibre strength utilization of the polyester component at the first break point when the cotton fibres are strained to their breaking point. In other words the polyester fibre should be in a position to share the maximum possible load at this point. Accordingly, the polyester fibres are tailor-made for blending with cotton.

Figure 8.6 depicts such a matching of cotton and polyester fibres. It may be noted that the stress–strain curve for this type of polyester is quite different from the normal polyester. This is high tenacity polyester, sometimes called cotton type polyester. An exercise by Ranganathan and Vengsarker[8] with viscose rayon as the second component has shown that the stress–strain curves of viscose rayon, given in Figure 8.7, closely follow that of medium-tenacity polyester.

The compatibility achieved in the aforementioned way optimized the yarn tenacity only. There would be many other situations where the matching is for a different end result. If the end product for a polyester-cotton blend happens to be shirting cloth, the hand of the fabric may take precedence over tenacity. It has been shown that these parameters can be considered in a quantitative way as these are well correlated with the compliance ratio. This ratio can be easily calculated from the stress–strain diagram of a fibre by using the following expression:

8.7 Stress–strain diagram of viscose rayon and polyester fibres.
1: 1.5 den × 51 mm viscose rayon; 0: 1.5 den × 51 mm medium
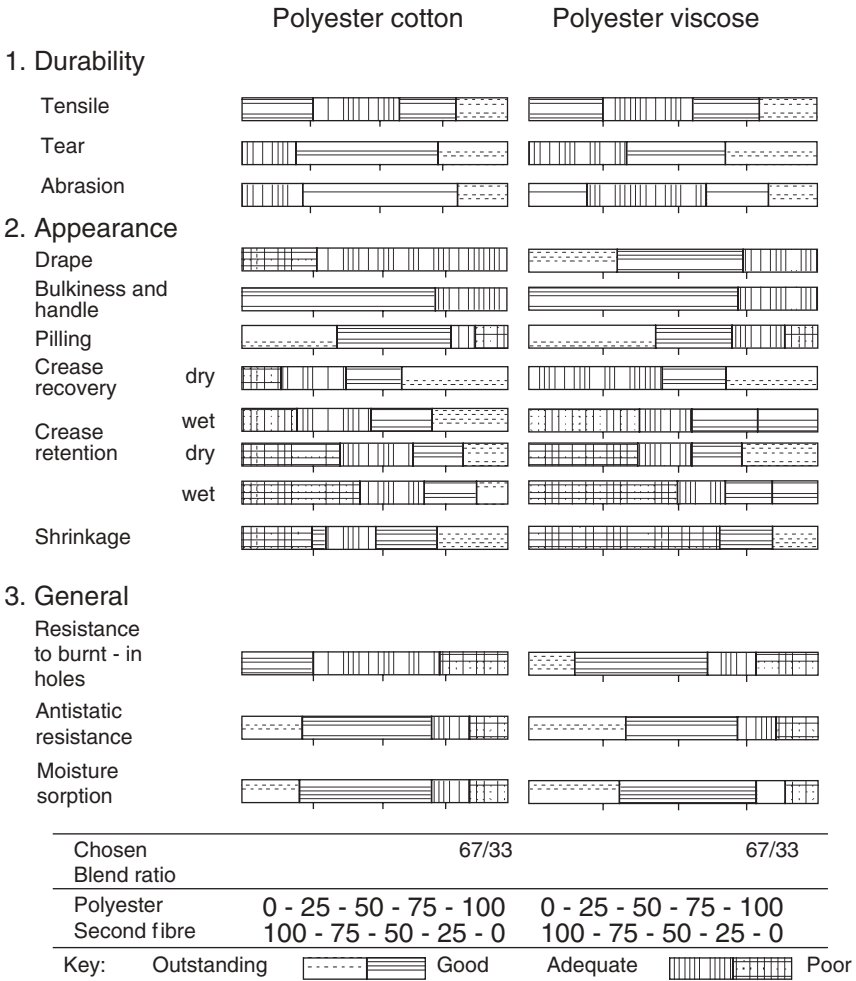tenacity polyester.

$$\text{Compliance ratio} = \frac{10S_{10}^{-1} - 5S_5^{-1}}{5}$$

where S_{10} and S_5 are the stress values in g/den at 10% and 5% fibre extension. Using this criterion the medium tenacity polyester is at the top of the category of moderate compliance ratio and high tenacity is at the bottom. Therefore, from the point of view of hand of the fabric, the obvious choice would be the medium tenacity polyester. The fact that the dye uptake of high tenacity polyester is less than that of medium tenacity fibre, the medium tenacity fibre may be preferred for general apparels. However, worldwide the blending of cotton is generally done with high tenacity polyester fibre (6.2–6.4 g/den).

8.7   Blend ratio

The blend ratio is generally calculated on the basis of conditioned weight (20 ± 2°C and 65 ± 2% RH in tropical countries, 27°C may be the secondary standard). Having decided the type of fibres and their specifications, the next critical decision to be made is in regard to the proportion of each type of fibre, i.e. the blend ratio, so as to optimize the desired properties in the fabric. Extensive research has been carried out on this aspect with various types of fibre blends.

Figure 8.8 gives a generalized view of results obtained in these studies. These are given in graphical form for various fabric properties such as tensile strength, tear strength, crease recovery, crease resistance, abrasion

	Polyester cotton	Polyester viscose

1. Durability

Tensile

Tear

Abrasion

2. Appearance

Drape

Bulkiness and handle

Pilling

Crease recovery — dry

Crease retention — wet

— dry

— wet

Shrinkage

3. General

Resistance to burnt - in holes

Antistatic resistance

Moisture sorption

Chosen Blend ratio	67/33	67/33
Polyester Second fibre	0 - 25 - 50 - 75 - 100 100 - 75 - 50 - 25 - 0	0 - 25 - 50 - 75 - 100 100 - 75 - 50 - 25 - 0

Key: Outstanding ⬚ Good   Adequate ⬚ Poor

8.8 Effect of blend ratio on properties of polyester blended fabrics.[1]

resistance, pilling, anti-static resistance, etc. for polyester-cotton and polyester-viscose fabrics. This figure can be used as a guideline for achieving the optimized fabric properties by selecting the proper blend ratio. It needs to be mentioned here that the yarn and the fabric construction as well as the final finishing of the fabric, especially with regard to heat setting and resin finishing, does make a noticeable difference in the desirable blend ratio. Another factor that influences the blend ratio is the stress–strain behaviour of the component fibres. In a polyester-viscose blend if the stress–strain curves of the two fibres do not match, the blend yarn is weaker at a low ratio of polyester. The optimum blend ratio would then work out to 65:35 for optimum wear performance. The polyester compo-

nent in the blend can be reduced to 50% if the fibres are made compatible in this respect. Some economic considerations, more than anything else, dictate the decisions about blend ratios that might otherwise look unreasonable.

8.8   Types of blending operation

8.8.1 Possibilities

Blending of staple fibres can be carried out at various process stages, using various methods, equipment, machines and intermediate products. The following can be distinguished:

Blending type	Process stage
Bale mixing	Before the blowroom
Flock blending	Within the blowroom
Lap blending	Using scutchers
Web blending	At the ribbon lap machine or the blending drawframe
Sliver blending	At the drawframe, the sliver-lap machine, or the comber
Fibre blending	At the card or the OE spinning
Roving blending	At the ring spinning machine

In addition, controlled and uncontrolled blending must also be distinguished. In uncontrolled blending, the components are brought together at random and without a mixing system (e.g. often in bale mixing). In controlled blending, the individual components are supplied to the machines in an ordered fashion and precisely metered (e.g. in weighing hopper feeders).

The various blending processes often differ strongly from one another with respect to capital cost, labour intensiveness, precision of blending, liability to error and simplicity. Each method has advantages and disadvantages. It is therefore not possible to put forward patent recipes for the use of one or another blending principle. The actual techniques used for blending of fibres can be referred to in the standard text books.

8.8.2 Optimum blending method

The objective of choosing a specific blending stage is to achieve the most homogeneous blend consistent with process performance, yarn quality and fibre waste. The most important factor influencing the choice of blending method is the type of fibres to be blended. In case the component fibres need similar opening and cleaning treatment, the blending may be resorted

to at the blowroom, and that, too, at the initial stages through stack or machine blending. This stage of blending is most suitable for blends like polyester-viscose as both these fibres are free from foreign impurities and trash and require mild opening action. The stack blending or sandwich method is simple and is generally used for blending of man-made fibres among themselves. The rayon component, which is rather more cohesive, may have to be pre-opened before blending.

Polyester and cotton, therefore, is normally blended at the drawframe. In certain instances, however, the mills using drawframe blending for polyester-cotton face serious problems in the carding of 100% polyester, and dye shade variations in the blend fabric due to poor homogeneity of the blend. Such mills can advantageously use blowroom blending so as to overcome these problems. The presence of cotton fibre along with polyester would avoid any difficulty faced in carding of 100% polyester fibre because the cotton fibres act as carrier fibres for the polyester fibres. The improved blend homogeneity obviates the problem of dye shade variation to a large extent. Blowroom blending would, however, require opened and cleaned cotton. Therefore, the polyester stock is blended with combed cotton sliver through stack blending. This practice obviously involves processing of cotton component twice through the blowroom and the card. Such overprocessing of cotton might result in more neps in the blend yarn. Blending drawframe would obviate the need for this practice, if poor blend homogeneity were to be the only problem. As mentioned earlier, the blending drawframe gives the same level of blend homogeneity as the blowroom blending.

8.9   Influence of fibre properties and blend ratio on yarn properties

8.9.1   Tenacity

The tenacity of blend yarns has been studied by many research workers. Invariably, it has been found that the yarn strength of blend yarn is lower than the weighted strength calculated from the respective strengths and proportions of the component fibres. One of the more logical and simple procedures was put forward by Hamburger[1,9] to predict the yarn tenacity with reasonable accuracy. This analysis has been represented graphically in Figure 8.9 for two components A and B for various possible stress–strain diagrams. The left-hand side shows the stress–strain behaviour of fibres and the right hand side the yarn tenacity for various blend proportions.

In all the three cases depicted in Figure 8.9, component A has lower breaking extension than component B. When a blended yarn is extended by applying a load, the fibres of the less extensible component A are
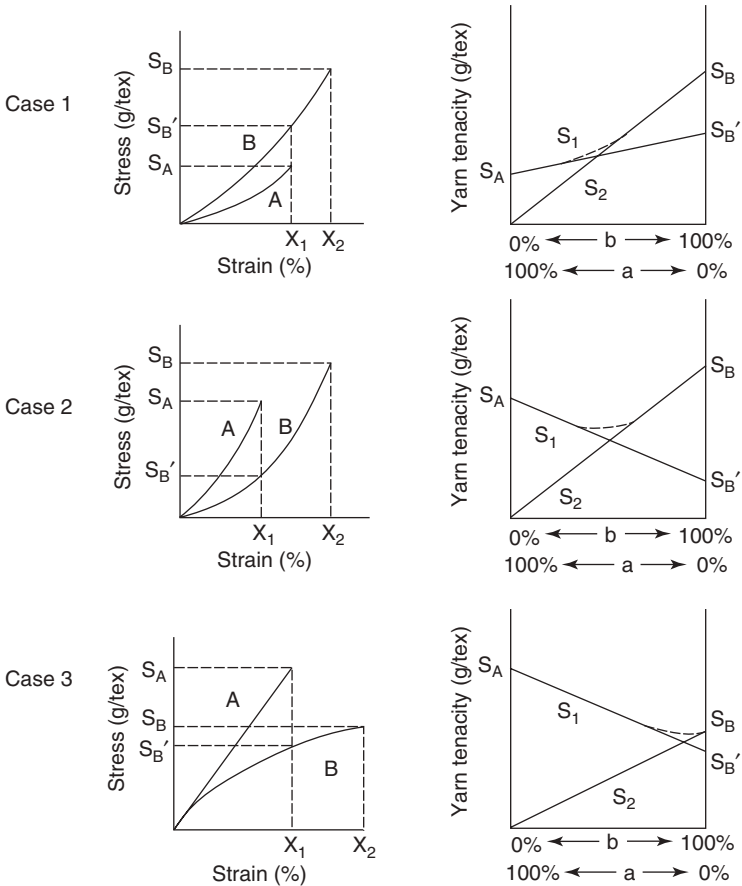
8.9 Effect of stress–strain diagrams of fibres on yarn tenacity with varying blend ratio.

strained to the breaking point first. This can be considered as the first rupture point, when all the fibres of component A are broken and the fibres of component B are partially stressed as per strain in the yarn. After this point the total load is borne by the fibres of the second component B. If component B is able to sustain the total load, the yarn reaches the second rupture point at a higher stress level. This is seen in cases 1 and 2. However, in the third case component B is not able to sustain the load and breaks immediately. These three cases are discussed here for prediction of yarn tenacity of blend yarns. Consider a blend yarn of tex T having 'a%' of fibre A and 'b%' of fibres B, then

$$T_A = \frac{aT}{100} \quad \text{and} \quad T_B = \frac{bT}{100}$$

where T_A is the tex of component A and T_B the tex of component B and $T_A + T_B = T$.

When the strain reaches $X1$, all fibres of component A will be on the point of breaking and the total load P_1 supported by the composite yarn will be the sum of the loads P_{1A} and P_{1B} supported by the two components.

Where

$$P_{1A} = \frac{aTS_A}{100} \quad \text{and} \quad P_{1B} = \frac{bTS'_B}{100}$$

if S_1 is the yarn tenacity at X_1, then

$$S_1 = \frac{P_1}{T} = \frac{1}{T}\left(\frac{aTS_A}{100} + \frac{bTS'_B}{100}\right)$$

$$= \frac{1}{100}(aS_A + bS'_B)$$

All fibres of component A will break at this point. For the second rupture point at X_2 when all fibres of B break, the total load P_2 supported by yarn would be the load supported by component B that is given by:

$$P_2 = P_{2B} = \frac{bTS_B}{100}$$

If S_2 is the tenacity at X_2 then

$$S_2 = \frac{P_2}{T} = \frac{1}{T}\left(\frac{bTS_B}{100}\right) = \frac{bS_B}{100}$$

Case 1: Fibre A has higher modulus but lower breaking stress and strain than fibre B. At the first rupture point when all fibres of component A break, the stress shared by the component B is lower than that of component A, i.e. $S_B > S_A > S'_B$. The resultant behaviour pattern of yarn tenacity shows that addition of the stronger and more extensible component B in small proportion reduces the yarn tenacity. It is only after a certain minimum % of B has been reached that the tenacity value becomes equal to that of 100% A component. Beyond this value, the tenacity shows a continuous increase. Such behaviour is expected for polyester-viscose and polyester-cotton blend yarns as shown in Figure 8.10, where cotton and viscose are like fibre A, and polyester like fibre B. This behavioural pattern can, however, change drastically if the type of polyester and viscose happen to be of high tenacity.

Case 2: Fibre A has lower modulus and lower breaking stress and strain than fibre B. In this situation, at the first break point when all the fibres of
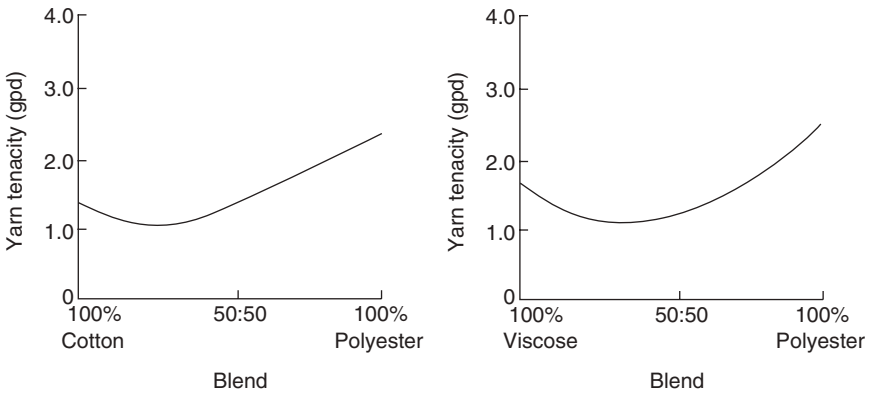
8.10 Effect of blend ratio on tenacity of polyester-cotton and polyester-viscose yarns.

component *A* break, the component *B* sharing a higher stress than that of component *A*, i.e. $S_B > S'_B > S_A$. Such a blend would therefore show a continuous increase in tenacity of blend yarn with increase in proportion of component *B*, i.e. stronger fibre. There is no drop in tenacity with addition of component *B* even in very low proportions. Such behaviour is expected from blends of higher tenacity polyester and viscose rayon, and polyester and acetate.

Case 3: In this case, unlike cases 1 and 2, component *B* has lower breaking stress though higher breaking extension. At the first breaking point, the load shared by component *B* is also lower than that of component *A*, i.e. $S_A > S_B > S'_B$. In such blends the addition of component *B*, the weaker one, reduces the yarn strength consistently and reaches the minimum value only when it is 100% component *B*. Such trends are observed when viscose or acetate is added to cotton. It must be mentioned here that the above analysis is applicable to single thread strength. The lea strength may show considerable deviation from these behavioural patterns because this test involves some other factors.

   It should be understood that the assumption that all fibres of component *A* break at the first breaking point, is not quite true. Many studies have shown that some of these fibres break twice or even thrice. Such multiple fibre breakage means that a part of the broken fibre is still in integral part of the yarn and is capable of load sharing. Referring to Figure 8.9 it would mean that for the second rupture point the point S_B should not have been joined with the origin but slightly higher. The extent of such load sharing by the less extensible fibres is quite difficult to estimate. However, one can safely say that the actual values of tenacities would lie above the predicted ones in the middle region. In spite of these limitations, the simple analysis

given here is of great help in understanding how the tenacity of fibres is realized in blend yarns, and gives a reasonably accurate prediction of yarn tenacity.

8.9.2 Breaking extension

Although yarn strength is considered to be the most important yarn property while selecting the right fibre for blending, the breaking extension of yarn should also be given due consideration. During shed formation in weaving, the breaking extension could significantly influence the weavability of the warp yarn. It is sometimes preferable to consider the work of rupture for this purpose.

In regard to this property, it has been found that an empirical approach is better suited. The change in breaking extension of a blend yarn with change in the blend ratio very much depends on the fibre extensibility of the blend components and the yarn structure. Figure 8.11 shows the breaking extension of some blend yarns at various blend levels. It can be seen that the shape of the curve is very different for the three blends. If the breaking extensions of the blend fibres are nearly equal as in the case of cotton and polynosic (C), there is practically no change in the breaking extension of the blend yarn. However, if the blend fibres have very different breaking extensions as in the case of cotton and polyester (A) or viscose and polyester (B) then there is an abrupt transition from a lower extension level to a higher extension level. In general, one could say that the breaking extension of a blend yarn lies in between the breaking extension of component yarns, that is the breaking extension of a polyester-cotton yarn
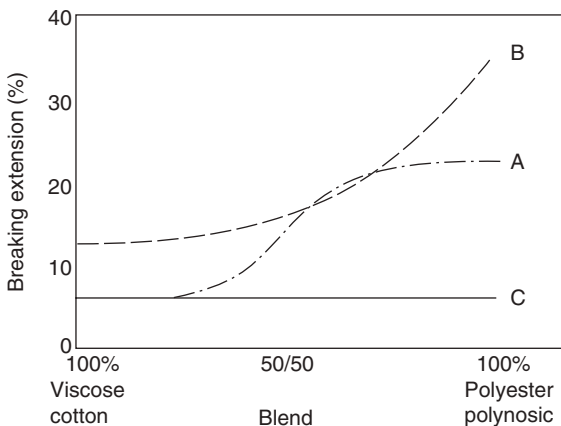
8.11 Effect of blend ratio on breaking extension of yarn:
A – Polyester-cotton, B – Polyester-viscose, C – Cotton-polynosic.

would lie in between the breaking extension of 100% cotton and 100% polyester yarns. However, it is rarely the arithmetic mean of the two. Unlike the yarn tenacity, it is extremely difficult to theoretically calculate the breaking extension of a blend yarn from the breaking extensions of the two components.

8.9.3   Yarn unevenness

Yarn unevenness is an important factor as far as yarn weavability and visual appearance of the fabric is considered. The main advantages of manmade fibres are the length uniformity and absence of short fibres. This results in improved drafting, as the fibre movement is under better control. This factor is of advantage in the blends of manmade fibres with cotton – especially carded ones – with a large length variation. Such length variation in 100% cotton mixing would give much higher irregularity during drafting (for example, as the viscose fibre content of appropriate length is increased in a cotton-viscose blend, the yarn irregularity goes down). For producing good quality yarns from polyester-cotton, it becomes essential, therefore, to improve the fibre length uniformity of the cotton component by combing it. The improvement in yarn evenness due to addition of manmade fibres is generally accompanied by a lower level of imperfections like neps, thick and thin places, and also of faults.
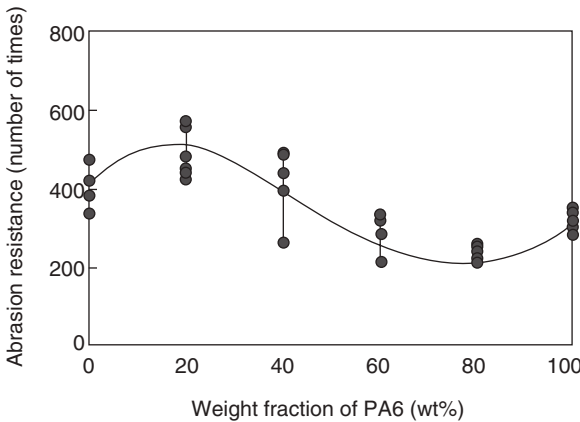
8.9.4   Abrasion resistance

It is supposed that abrasion resistance of the blend fibre is greatly affected by the component existing on the fibre surface. To find the composition at the fibre surface, the infrared reflection absorption spectrum was measured by the FTIR-ATR method. The result reveals that, with increase in PA6 content, its existence on the surface also increases.

To make high abrasion resistance fibres, polypropylene/polyamide 6 blend fibres of different blend ratios and viscosity ratios are being prepared by Takahashi et al.[10] They finally concluded that the relationship between abrasion resistance and blend ratio of the blend fibres is found to be in a reverse-S-shaped curve as shown in Figure 8.12. The abrasion resistance increases with increase in PA6 content up to 20% of PA6 and then it follows a decreasing trend up to 60%. The abrasion resistance curve increases again as PA6 content approaches 100%. The result of the drawn fibre also shows a similar trend as can be observed from Figure 8.13.

In a blend fibre with the PA6 content range of 0–20%, the relatively rich PP component probably gives a sufficient wax effect to the surface of the blend fibre. In the PA6 content range of 0–20%, the breaking strength of the fibre itself increases, since the proportion of the PA6 component with
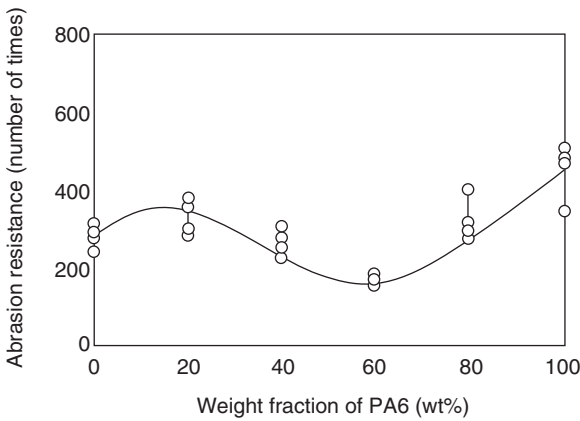
8.12 Relationship between abrasion resistance and weight fraction of PA6 for the as-spun blend fibres.


8.13 Relationship between abrasion resistance and weight fraction of PA6 for the drawn fibres ($\lambda = 4.8$).

high breaking strength increases as the PA6 content increases. The number of repetitions till abrasive rupture might have increased as the PA6 content increased. In the blend fibre whose PA6 content is more than 60%, another reason why the abrasion resistance increased with increasing the PA6 content might be the change of cross-sectional shape of the fibre.

8.10   Blended yarn structures

Kemp and Owen[11] conducted experiments wherein blend yarns were extended to different levels of strain and then were taken apart. The
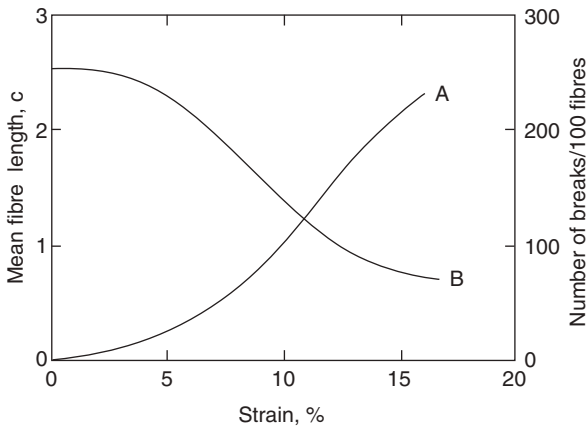
8.14 Mean fibre length and fibre breaks in a nylon-cotton blend.

numbers of breaks of cotton fibres were then measured and the mean length of the cotton fibres was calculated. The breaks and the mean length are plotted for a 60/40 nylon-cotton blend in Figure 8.14 and here it is seen that a few fibres break at yarn extensions of 5% extension, but this number raises to 50 breaks at an 8% extension, to 100 breaks at a 10% extension, and to over 200 breaks at 15% extensions. The mean length of the fibre reduces correspondingly.

They also demonstrate that the resistance of the yarn to extension can be calculated from the weighted resistance of its individual components up to the level of about 6 or 7% extension, corresponding to the point where the lower extension fibre starts to break. Beyond this point it is necessary to determine the loss in load capacity due to the broken fibres, but also to take into account the further ability of the cotton fibre segments to contribute to the yarn tensile resistance. The assumption of the complete independence among the fibres of the yarn would lead one to predict that beyond 8% extension the yarn would have to depend entirely upon its nylon component, and there would be a significant drop in the load level at this point of the yarn extension test.

Machida[12] predicted the stress–strain behaviour in a blended yarn and of the strength of yarns with varying blend ratios (Figure 8.15 (a)). His prediction was based upon the assumption of independent behaviour among the fibres of the yarn proposed by Hamburger.[9] Figure 8.15 (b) shows the change in the height of the two rupture points which occur at the strains corresponding to the rupture strains of the individual fibre components. The yarn breaking strength is taken to be that rupture point which is higher for a given blend ratio.
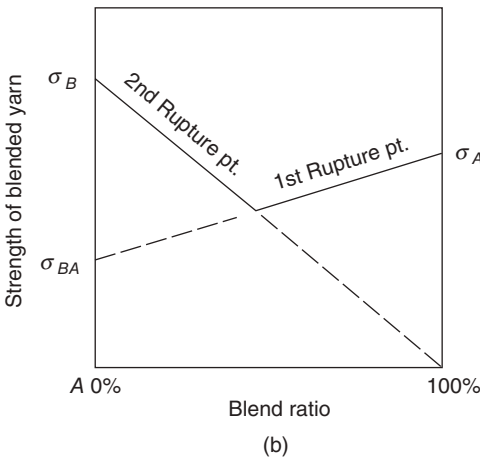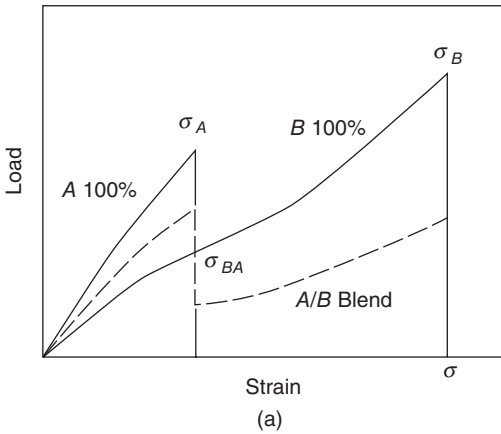
8.15 (a) Stress–strain curves of blend components; (b) strength of blended yarn.

Figure 8.16 shows the load-extension behavior of 4000 den model yarns made up of individual 70/34 nylon yarns and 100 s cotton yarns with a twist multiple of 3. The importance of fibre contribution to yarn strength adds significantly to the breaking energy of the yarn structure. Furthermore, it may be expected that when the blended yarn is introduced into a woven structure, the lateral force further enhances the contribution of cotton component to the breaking strength of the fabric at strain levels exceeding those of the cotton fibre. In Figure 8.17 there is clear indication that the actual breaking strength of the blended yarn falls above the predicted curve.
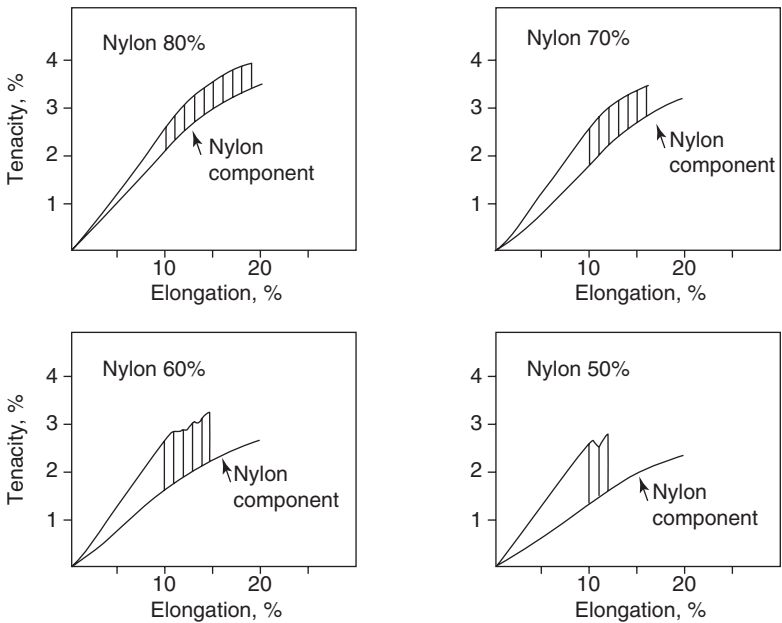
8.16 Tensile behaviour nylon-cotton blends.[13]
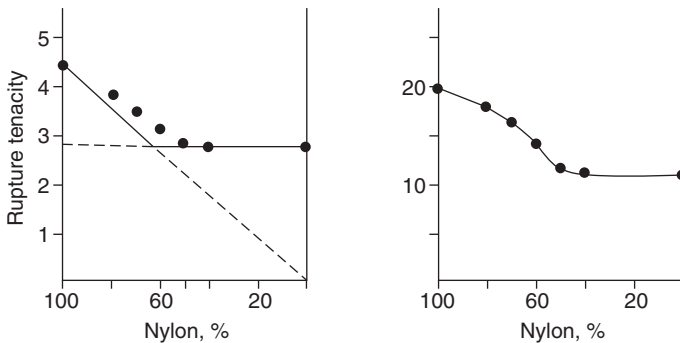
8.17 Tensile behaviour nylon-cotton blends.[13]

Furthermore, it is seen in Figure 8.17 that the tensile resistance of the blended yarn does not fall off rapidly after a 10% extension. The shaded portion in the stress–strain curves indicates the extent to which cotton, which must have ruptured at least once by now, continues to contribute to the resistance of the nylon-cotton blend. The question to which this study was addressed was how the broken lengths varied with strain and how they
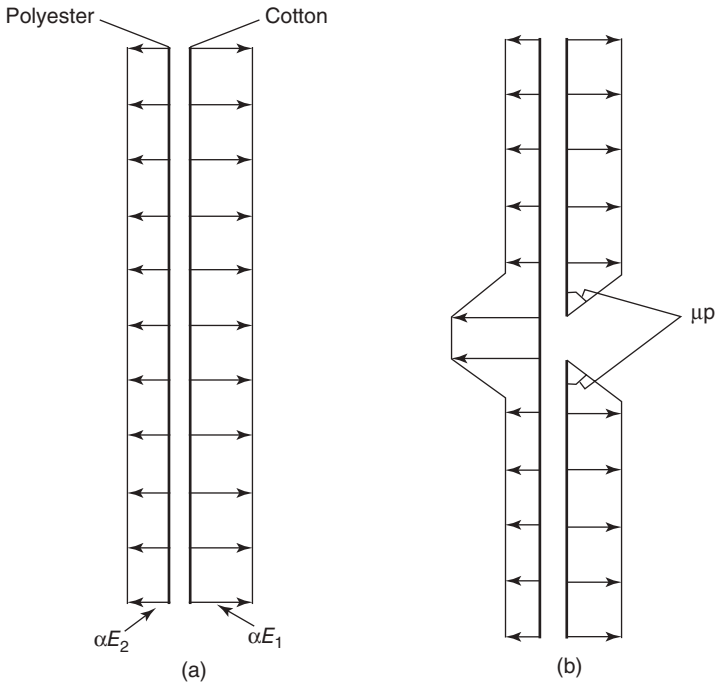
8.18 Stress transfer between fibres.[13]
(a) 2% elongation, (b) 10% elongation. (α) local strain; (E) tensile
modulus; (μ) coefficient of friction; (p) local pressure.

varied with the structure of the yarn and their individual positions within
that yarn. Note that this experimental work was done with model yarns in
which the individual components, instead of being single fibres, were actu-
ally twisted yarns of nylon or of cotton.

The final question which remains, relates to the fibres which surround
the cotton just at the moment that it breaks. As seen in Figure 8.18, the
modification of the tensile distribution along the cotton fibre which occurs
when breakage takes place somewhere between 2% elongation and 10%
elongation must be accompanied by a corresponding modification of the
tensile distribution along the adjacent closely packed blend fibre, in this
case a polyester. Note in the right portion of Figure 8.18, that over the
ruptured region of the cotton the neighbouring polyester fibre must suffer
a much higher level of local stress, perhaps sufficient to cause its immediate
rupture.

Clearly, one must now consider the relative strength level of cotton
versus polyester so as to determine whether the rupture of the cotton will
cause a catastrophic propagation of the breakdown to the surrounding
blend fibres. The chances are that if the cotton is surrounded by other

cotton fibres in close contact, the break will propagate, since the surrounding cotton fibres would have already been loaded to a point very close to their breaking limit. Also, the additional load to be shared because of the breakdown of a neighbour would exceed their strength. Failure of the second and third and third and fourth cotton fibres in a location would not only increase the local load to be shared by adjacent fibres, but would also tend to reduce the pressure locally and thus cause increased slippage. One could consider an infinite number of variations of yarn breakdown, but it suffices to say that successful taking over of the load forfeited by an individual fibre by neighbouring fibres is desirable in an efficient blend yarn structure. And this would dictate the desirability of good dispersion of the fibres, that is, a minimum amount of clumping. Also, it would suggest the desirability of having the higher elongation fibre break at a tensile value considerably above that of the lower elongation fibre. Without this provision, it is likely that the blend yarn will fail catastrophically and the full tensile energy of the more extensible fibre components will not be realized.

8.11   Blending for speciality products

8.11.1 Core spun yarn

Core spun yarn has the strength and elongation of the central component and exhibits most of the other characteristics of the surface staple fibres. These yarns are widely used in a variety of applications; such as industrial clothing, conveyor belting, tentage and sewing threads. Core spun yarns can be manufactured by different methods like ring spinning, open end spinning, air jet spinning and friction spinning by the incorporation of certain attachments. In the case of staple fibre spun yarn, no single fibre is present parallel to the yarn axis due to the migration of an individual component. Migration occurs if all the components are delivered into the twisting zone at the same speed. In a true core yarn, therefore, the length of the component forming the core must be lower than the corresponding lengths of the covering component. The vital requirement for the ideal core yarn is that the covering fibres should enclose the core in a regular manner so that the core is completely buried at all points along the yarn length.[14]

Different methods for manufacturing core spun yarns

Core spun yarn can be manufactured by different methods like ring spinning, open end spinning, air jet spinning and friction spinning. In industry,

Table 8.1 Tenacity, CV% of tenacity and elongation of core yarns[14]

Count (Ne)	34 denier filament (25% core)			50 denier filament (35% core)		
	Tenacity (g/tex)	CV of tenacity (%)	Elongation %	Tenacity (g/tex)	CV of tenacity (%)	Elongation %
30s C	13.6	12.8	7.9	14.9	7.0	8.0
30s K	11.4	9.8	6.8	12.4	8.0	8.0
40s C	12.9	8.8	6.8	15.1	4.5	9.0
40s K	12.3	10.2	6.3	14.4	8.0	7.5

Table 8.2 Evenness and imperfections of core yarns[14]

Count (Ne)	34 denier filament (25% core)		50 denier filament (35% core)	
	U%	Imperfections/km	U%	Imperfections/km
30s C	15.5	1915	12.4	685
30s K	17.1	2563	16.0	2521
40s C	14.8	1539	13.6	1028
40s K	16.8	3302	15.2	2340

ring spinning system is popular for producing core spun yarn. It is possible to manufacture core yarns by making simple modifications in existing conventional or hi-tech ring frames. The description of the modifications can be found in the literature.[14]

Core yarn is composed of two components, core and the sheath. The twisted central component of the core spun yarn lying parallel to the yarn axis, is termed as 'core'. The core component may be mono- or multifilament. The outer twisted component covering the core is termed as 'sheath'. Sheath fibres are either natural or manmade fibres. The properties of ring spun core yarn depend mainly on core-sheath ratio, and pre-tension applied to the core material. The core-sheath ratio depends on the core filament denier and yarn count. The major properties of ring spun core yarns (30s and 40s Ne) for different core-sheath ratios are given in Tables 8.1 and 8.2. The proportions of sheath (cotton) and core (polyester filament) used in these yarns are given in Table 8.3.

Yarn quality attributes are better with higher core component. To illustrate, when the core content is increased from 25 to 35%, yarn tenacity increases by 9% in 30s count and about 17% in 40s count. Breaking

Table 8.3 Proportion of sheath and core[14]

Count of core yarn	Core filament denier	Proportion of sheath/core
30s	34	75/25
	50	62/35
40s	34	78/22
	50	68/32

elongation also improves by 1 to 2% (absolute values) and CV of tenacity reduces by 2 to 6% (absolute values). Evenness improves by 1 to 3% and imperfections deacrease by about 35% when the core content is increased from 25 to 35%.

Core yarns are also manufactured in rotor spinning systems with a view to obtain higher productivity. For producing core yarn by open end spinning process, it is necessary to make some modifications in the conventional rotor spinning machinery. The modification of the rotor spinning process can be found in the literature.[15] The advantages of producing core yarns on rotor spinning system, according to Lawrence and Chen[16] are, (a) the rotor-spun core yarn is more likely to retain all the strength contributed by the core component and the full length of the core component, since the continuous filaments are not twisted during spinning and will therefore not suffer twist contraction, (b) an important consequence of this is that even metallic wires of high rigidities can be used as core, (c) the evenness of rotor-spun core yarns is better than that of equivalent ring spun yarn, and (d) the bulkiness of the rotor-spun core yarns is greater than that of the equivalent ring spun structure. Hence a reduction in cloth set will be required to obtain the same cover from rotor spun core yarns. Core yarns are also produced in DREF-2 and DREF-3 and air-jet spinning processes. The details may be found in the literature.[14]

## 8.11.2 Blending in nonwoven and other products

Polyester polymers and copolymers are widely used in nonwovens in both staple fibre and spunbonded processes. The combined volume of polyester and polyolefin polymers used in the United States in nonwoven fabrics has been estimated to be more than 250 million kg annually. Blends of polyester fibres with wood pulp which are wet laid and then bonded by hydro-entangling and subsequently treated with a repellent coating are widely used in disposable surgical gowns and drapes. Nylon fibres are used only

sparingly in the form of staple fibres and in a limited volume in spunbonded nonwovens. One of the largest uses for spundbonded nylon nonwovens is in the reinforcement of carpet pads and in fibreglass filters. The fabrics provide a low friction surface to carpet pads that facilitates the installation of carpets.

Blends for filtration application

Fine diameter fibres have always been of interest in filtration applications. A series of segmented synthetic splittable fibres has been developed that will split when processed through gentle carding systems such as cotton and semi-worsted cards. The fibres are produced from polyester and nylon 6 and are spun into a 16-segment 3 dpf × 51 mm crimped fibre (for cotton system) and other lengths and deniers can be produced for the semi-worsted system. The individual split fibre segments have effective diameters in the range of between 3–4 microns. The fibre is blended up to 30% of the fibre blend with other fibres. The fibre must be properly preblended and opened to maximize blend uniformity before carding. Worker and stripper loading must be considered when running this fibre because the split fibre has 16 times the number of fibres that must be processed through the system. A number of other polymer combinations are under development including polypropylene for electrostatic charging and blends of polymers for enhanced triboelectric properties. Figure 8.19 shows the fibre before carding.

Figure 8.20 is a cross-sectional photomicrograph of the card-split fibre. The individual split segments can be clearly seen. Notice that the fibre
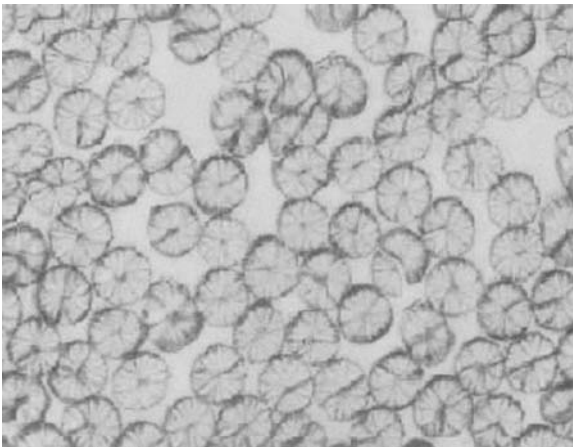
8.19 Photomicrograph of card-splittable fibre before splitting.[17]
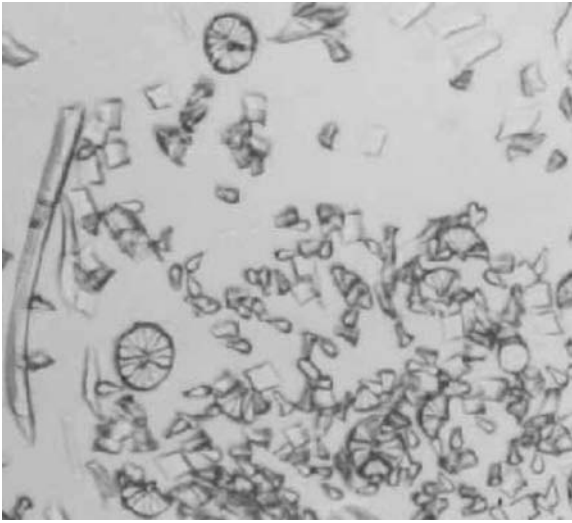
8.20 Cross-sectional photomicrograph of card-splittable segmented fibre after carding.[18]

Table 8.4 Wetlaid splittable fibre versus commercial meltblown physical property comparison

Property	Wetlaid short cut nylon 6/Polypropylene	Commercial meltblown
Basis weight (gm^{-2})	55	65
Frazier permeability (cfm@ 0.5″ H$_2$O)	265	250
1st Bubble (″H$_2$O diesel fuel)	4.0	4.2
Thickness (mils)	14	14
Strip tensile (lb/inch)	1.0	0.3

segments are pie-shaped. This shape should be an advantage in filtration materials for lowering the clean pressure drop of materials produced from these fibres. Splittable synthetic fibres have been produced in short cut form with a water dispersible finish. Polymer blends include polypropylene/nylon 6 and polypropylene/polyester. The fibres have been produced as 16-segment 4.1 dpf × 0.24″ without crimp. When formed into handsheets with minimal opening processing, the physical properties of the handsheets match those of commercially available meltblown polypropylene materials as shown in Table 8.4. Split fibre segments range from 3–4 microns. Order of addition of furnish components will need to be addressed for each specific fibre blend produced.

These fibres have been successfully processed in fibre blends through a Rando Webber as high as 50% of the fibre blend. The fibre opened and split well in the machine and produced a uniform product with micro-denier fibre segments. When a card is used as part of the fibre opening system for the Rando (or the airlaid process is a Fehrer-type system), care should be taken to select a splittable fibre blend percentage that will successfully process through the card without jamming the worker and stripper sections.

The wetlaid shortcut version of the fibre has been successfully processed through a DanWeb Forming airlaid system up to 90% of the fibre furnish. The fibre was fed to the unit through a transport fan that opened and split the fibre into individual segments and formed it into an airlaid sheet. The resultant web was bonded with 10% binder fibre and was extremely soft to the touch. Blends with woodpulp and other fibres are expected to process well and can carry the splittable fibre through the hammermill section, if needed. Blend levels will require definition for each specific application.

Splittable synthetic fibres have been produced with cross-sections that will split when subjected to high-pressure water jets without splitting in the card. The fibres are processed as-spun into nonwoven products as standard textile fibres. The web is then passed through a hydroentanglement unit that splits the fibres and causes them to wrap around themselves and other fibres in the blend to enhance the tensile and toughness properties of the product.

Blends with recycled fibres

The textile industry provides ideal opportunities for developing technology for the use of recycled, reprocessed, or low-grade fibres to produce environmentally acceptable textile products. Many areas of textile processing for both garments and household goods produce waste materials that can be recycled into usable consumer products. More than 400 million tonnes of non-biodegradable polyester remnants are produced as waste each year. Such wastes provide good sources of materials for recycled products. In addition, most commercial cotton textile processes require that the fibres be scoured and bleached. Use of greige cotton in consumer products would not only reduce production costs, but would eliminate the discharge of chemicals needed in the scouring and bleaching process.

In a study,[19] nonwoven blanket materials have been made from blends of recycled polyester fibres and greige cotton. Blending of cotton fibres into these nonwovens allowed application of finishes previously developed for cotton fibres. Nonwoven fabric structure was chosen because they are less expensive to produce than wovens, or knits, and because the short reprocessed polyester fibres could better be utilized in nonwoven processes.

Crosslinking finishes increased the stability of the fibres within the fabric, and also enhanced flame resistance. Finished fabrics withstood five laundry cycles without losing acceptable appearance or structural integrity. An antibacterial finish provided protection on unlaundered samples, but lost effectiveness as the laundering progressed. The fabrics were light-weight, had good hand, and excellent comfort and thermal qualities. These materials were expected to provide highly acceptable thermal coverings for refugee, medical, military, and recreational uses where a low cost, short-term use product is desired.

8.12   Summary

Polyester and polyamide fibres have interesting properties and these properties can be engineered to a specialized application during the process of manufacture. However, it is still not possible to obtain all the required properties for a particular application due to the inherent nature of these fibres. In these cases, it becomes essential to blend these fibres with other suitable fibres to enhance their properties. In this chapter, application of blending to three segments of applications, namely apparel end uses, core spun yarn applications and nonwoven and other applications are discussed in detail. Special attention has been provided on the evaluation of blending. Issues related to influence of fibre parameters on the blending behaviour as well as on structure and properties of the final yarn produced are discussed in length. In the case of blending of polyester and polyamide fibres for speciality products, core spun yarns, use of splittable fibres for making nonwoven filter products and blends using recycled fibres are discussed.

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