Kirk-Othmer Encyclopedia of Chemical Technology.

FIBERS, ELASTOMERIC

Elastomeric fibers can be made from natural or synthetic polymeric materials that provide a product with high elongation, low modulus, and good recovery from stretching. Currently, these fibers are made primarily from polyisoprenes (natural rubber) or segmented polyurethanes and to a lesser extent from segmented polyesters. In the United States the generic designation spandex has been given to a manufactured fiber in which the fiber-forming substance is a long-chain synthetic polymer comprised of at least 85% of a segmented polyurethane (1); in Europe the equivalent term elastane is commonly used.

The experimental production of elastomeric fibers based on segmented polyurethanes was first reported in the early 1950s by Farbenfabriken Bayer, a pioneer in urethane and diisocyanate chemistry (2, 3). This was followed by semi-commercial-scale production of polyurethane-based fibers by the Du Pont Co., in the late 1950s (4, 5). Prior to development of the polyurethanes, most elastomeric fibers were made with natural rubber. Two processes were used: slitting rubber sheets to produce cut rubber threads or extruding rubber latex into an acid coagulation bath followed by washing, drying, and curing. Smaller amounts of cut rubber threads have also been produced from synthetics such as neoprene and nitrile rubbers especially where improved solvent resistance is required. Fiber cross-sections are square or rectangular for cut rubbers and essentially round for extruded latex threads.

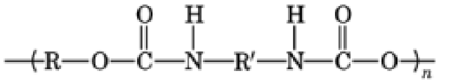
Thermoplastic, inelastic fibers, such as nylon and polyester, may be processed to provide spring-like, helical, or zigzag structures. These fibers can exhibit high elongations as the helical or zigzag structure is stretched, but the recovery force is very low. This apparent elasticity results from the geometric form of the filaments as opposed to elastomeric fibers whose elastic properties depend primarily on entropy changes inherent within their polymer structure. Thus processed inelastic fibers must comprise a significant portion of a stretch fabric whereas an elastomeric fiber provides the necessary stretch properties at 5–20% of fabric weight.

Other elastomeric-type fibers include the biconstituents, which usually combine a polyamide or polyester with a segmented polyurethane-based fiber. These two constituents are melt-extruded simultaneously through the same spinneret hole and may be arranged either side by side or in an eccentric sheath–core configuration. As these fibers are drawn, a differential shrinkage of the two components develops to produce a helical fiber configuration with elastic properties. An applied tensile force pulls out the helix and is resisted by the elastomeric component. Kanebo Ltd. has introduced a nylon–spandex sheath–core biconstituent fiber for hosiery with the trade name Sideria (6).

Nonspandex elastomeric fibers based on segmented polyesters and polyesters are currently being developed that can be melt-spun into threads (7). Teijin Ltd. produces an elastomeric fiber of this type with the trade name Rexe.

1. Mechanical Properties

In both rubber thread and spandex fibers, mechanical properties may be varied over a relatively broad range. In rubber, variations are made in the degree of cross-linking or vulcanization by changing the amount of vulcanizing agent, usually sulfur, and the accelerants used. In spandex fibers, many more possibilities for variation are available. By definition spandex fibers contain urethane linkageswith the following repeat structure (1):



$$-\!\left(R-O-\overset{O}{\overset{\|}{C}}-\overset{H}{\overset{|}{N}}-R'-\overset{H}{\overset{|}{N}}-\overset{O}{\overset{\|}{C}}-O \right)_{n}\!-$$

The number of polymers in the classification is obviously very large. Most urethane polymers (qv) in current use for the manufacture of spandex fibers are made by the reaction of 1000–4000 molecular weight hydroxy terminated polyethers or polyesters with a diisocyanate at a molar ratio of ca 1:1.4 to 1:2.5, followed by reaction of the resulting isocyanate-terminated prepolymer with one or more diamines to produce a high molecular weight urethane polymer. Small amounts of monofunctional amines may also be included to control polymer molecular weight. Mechanical properties may be affected by changing the particular polyester or polyether glycol, diisocyanate, diamine(s), and monoamine used; they can be further modified by changing the molecular weight of the glycol and by changing the glycol–diisocyanate molar ratio (8, 9).

The long-chain urethane polymer molecules in spandex fibers are substantially linear block copolymers comprising relatively long blocks in which molecular interactions are weak, interconnected by shorter blocks in which interactions are strong. The weakly interacting blocks, commonly referred to as soft segments, are from the polyether or polyester glycol component whereas the blocks having strong interactions result from diisocyanate and chain extender reactions and are referred to as hard segments. The hard segments are usually aromatic–alipathic ureas that connect with the soft segment through urethane linkages. With fiber formation, hard segments from several chains associate into strongly bonded cluster domains. These form islands of a discontinuous phase and convert the polymer to a three-dimensional network (10). The principal interchain forces are hydrogen bonds between NH groups and carbonyls, but crystallizability is also favored by the rigid and planar configuration of the aromatic rings. Interchain bonding must be not only strong enough to prevent molecular slippage, but also concentrated so that the connecting soft segments can comprise a large fraction of the polymer chain. This result in high stretch along with low modulus. Urea hard segments that comprise less than 25% of polymer mass provide this needed concentrated bonding force. In contrast, the network structure in rubber depends on covalent bonds between chain molecules that result from vulcanization with sulfur. In both polyurethanes and rubber, modulus is directly related to tie-point density. Similarly, the relationship for maximum elongation is an inverse function of tie-point density. In rubber fibers, tie-point density is controlled by the amount of vulcanizing agent, accelerant, and reaction conditions. In polyurethanes, tie-point (hard segment) density is controlled by the soft segment molecular weight and the molar ratio used to prepare the glycol–diisocyanate prepolymer.

The physical characteristics of current commercial rubber and spandex fibers are summarized in Table 1. Typical stress–strain curves for elastomeric fibers, hard fibers, and hard fibers with mechanical stretch properties are compared in Figure 1.

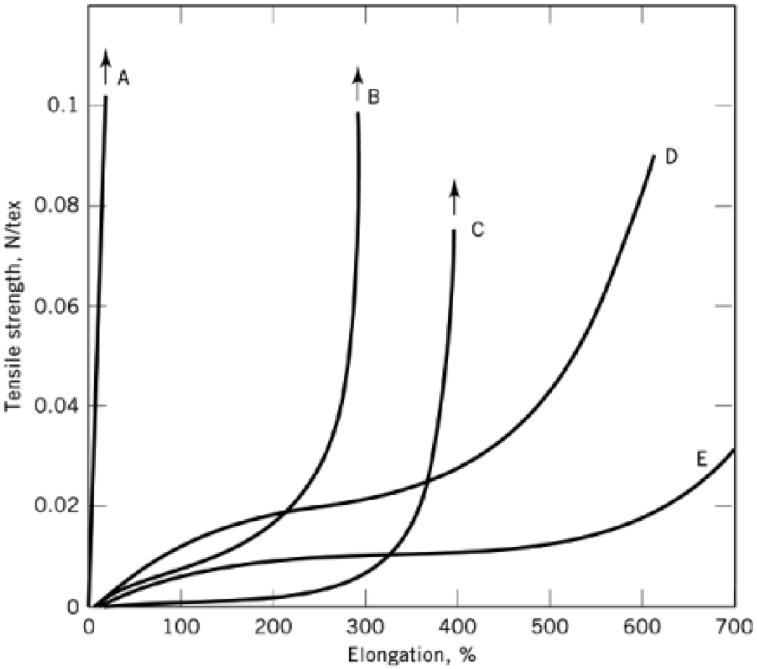


Fig. 1. Stress–strain curves: A, hard fiber, eg, nylon; B, biconstituent nylon–spandex fiber; C, mechanical stretch nylon; D, spandex fiber; E, extruded latex thread. To convert N/tex to gf/den, multiply by 11.33.

Table 1. Physical Properties of Elastomeric Fibers

Property	Spandex	Extruded rubber	Cut rubber
sizes available[a]	1.1–250 tex[b]	16–610 tex[b]	2.5–21 μm dia[c]
tenacity, N/tex[d]	0.05–0.13	0.02–0.03	0.01–0.02
elongation, %	400–800	600–700	600–700
modulus[e], N/tex[d]	0.013–0.045	0.004–0.005	0.002–0.004
stability[f]			
uv light	good	fair	fair
ozone	good	poor	poor
NO_x	fair, yellows	poor	poor
active Cl	fair, yellows	poor	poor
body oils	fair	poor	poor
cosmetics	good	fair	fair
dyeability	dyeable	not dyeable	not dyeable
abrasion resistance	very good	poor	poor

[a] Spandex size is usually expressed in denier which is weight in g/9000 m length. However, the SI unit is tex, the weight in g/1000 m. Rubber size is expressed as gauge, which is the reciprocal of diameter or size in inches.

[b] To convert tex to den, multiply by 9.09.

[c] 1,200–10,000 gauge.

[d] To convert N/tex to gf/den, multiply by 11.33.

[e] First cycle stress at 300% elongation.

[f] Both spandex fibers and rubber threads normally contain antioxidants and other stabilizers.

Table 2. Producers of Spandex and Related Fibers

Company	Process	Trade name
	North America	
Canada		
Du Pont	dry-spun	Lycra
Mexico		
Du Pont/Nylmex	dry-spun	Likra
United States		
Du Pont	dry-spun	Lycra
Globe Manufacturing	reaction-spun and dry-spun	Glospan, Cleerspan
	South America	
Argentina		
Du Pont	dry-spun	Lycra
Brazil		
Du Pont	dry-spun	Lycra
Venezuela		
Spandhaven	wet-spun	Gomelast
	Europe	
Germany		
Bayer AG	dry-spun	Dorlastan
Italy		
Fillattice	wet-spun	Lyneltex
the Netherlands		
Du Pont	dry-spun	Lycra
Russia		
(licensed from Toyobo)	dry-spun	VCE
United Kingdom		
Du Pont	dry-spun	Lycra
	Asia	
Japan		
Asahi Chemical Industry	dry-spun	Roica
Du Pont/Toray	dry-spun	Opelon
Fuji Spinning	wet-spun	Fujibo
Kenbo	melt-extruded	Loobell
	melt-extruded	Sideria[a]
Kuraray	melt-extruded	Spantel
Nisshinbo	melt-extruded	Mobilon
Teijin	melt-extruded	Rexe[b]
Toyobo	dry-spun	Espa
Korea		
Dong Kook	wet-spun	Texlon
Tae Kwang	dry-spun	Acelan
People's Republic of China		
(licensed from Toyobo)	dry-spun	Yantai
Singapore		
Du Pont	dry-spun	Lycra

[a] Nylon–spandex sheath–core biconstituent fiber.
[b] Segmented polyester elastomeric fiber.

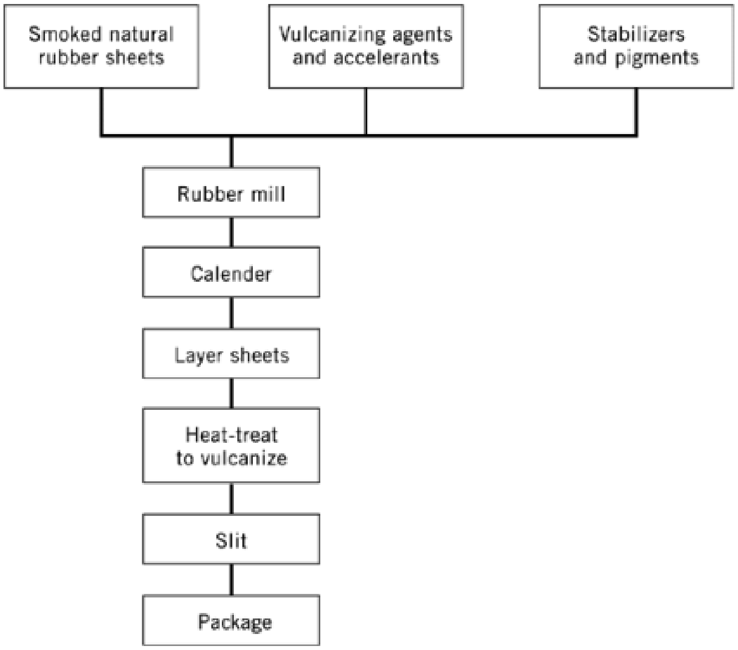


Fig. 2. Cut rubber thread manufacture.

2. Manufacture

2.1. Cut Rubber

To produce cut rubber thread, smoked rubber sheet or crepe rubber is milled with vulcanizing agents, stabilizers, and pigments. This milled stock is calendered into sheets 0.3–1.3 mm thickness, depending on the final size of the rubber thread desired. Multiple sheets are layered, heat-treated to vulcanize, then slit into threads for textile uses (Fig. 2). Individual threads have either square or rectangular cross-sections.

2.2. Extruded Latex Thread

In the manufacture of extruded latex thread, a concentrated (up to ca 50% solids) natural rubber latex is blended with aqueous dispersions of vulcanizing agents, stabilizers, and white pigments. This compounded latex is held under controlled temperature conditions until partial vulcanization occurs. This has the effect of increasing wet strength and thus the processibility of the extruded threads. The matured latex is extruded at constant pressure through precision-bore glass capillaries into a 15–55% acetic acid[64-19-7] bath where coagulation into thread form occurs. Threads are removed from the coagulation bath by transfer rollers, washed free of excess acid with water, and conducted through a dryer, after which a silicone oil-based finish is applied and the threads are formed into multiend ribbons. The ribbons are then vulcanized by multiple passes on a conveyer belt through an oven that can increase curing temperature in stages up to about 150°C. After vulcanization the multiend ribbons are packed without support in boxes for shipment to the customer. A typical extruded latex thread production line is shown in Figure 3. Latex thread production rates vary with thread size and equipment but, owing to hydrodynamic drag and the weak nature of the coagulating thread, maximum line take-up speeds are about 30 m/min.

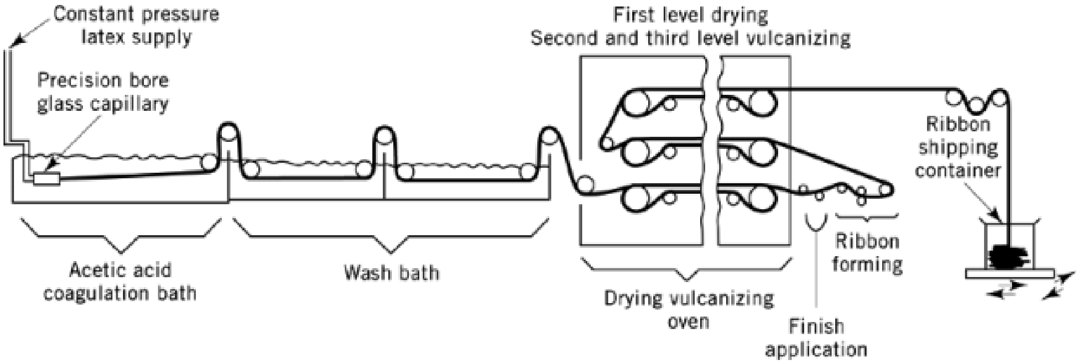


Fig. 3. Extruded latex thread production.

2.3. Spandex Fibers

Four different processes are currently used to produce spandex fibers commercially: melt extrusion, reaction spinning, solution dry spinning, and solution wet spinning. As shown in Figure 4, these processes involve different practical applications of basically similar chemistry. An isocyanate terminated prepolymer is formed by the reaction of a 1000–4000 molecular weight macroglycol with a diisocyanate at a glycol–diisocyanate ratio that may range from 1:1.4 up to about 1:2.5. The soft segment macroglycol can be either a polyether, a polyester, a polycarbonate, hydroxyl-terminated polycaprolactone, or a combination of these. The prepolymer subsequently reacts with either a glycol or diamine(s) at near stoichiometry; a small amount of monofunctional amine may be included to control final polymer molecular weight. If the diol or diamine(s) reaction with the prepolymer is carried out in a solvent, the resulting block copolymer solution may be wet or dry spun into fiber. Alternatively, the prepolymer may be reaction spun by extrusion into a bath containing diamine to form a fiber, or the prepolymer may be permitted to react in bulk with a diol and the resulting polymer melt extruded in fiber form.

2.3.1. Melt Spinning

Currently, the principal producer of melt-spun spandex fibers is Nisshin Spinning Co. in Japan. However, melt-spun spandex fibers are also produced by Kanebo and Kururay Co., also in Japan. Because of thermal stability constraints, only polymers that contain all urethane hard segments (glycol extended) can be melt-extruded. The intermolecular association between all urethane hard segments is inherently weaker compared with urea-based hard segments produced from diamine extenders; melt-spun fibers are normally made at higher diisocyanate–glycol ratios which in effect produce a relatively longer hard segment to compensate for the weaker intermolecular bonding forces.

More recently, melt-spun biconstituent sheath–core elastic fibers have been commercialized. They normally consist of a hard fiber sheath (polyamide or polyester) along with a segmented polyurethane core polymer (11, 12). Kanebo Ltd. in Japan currently produces a biconstituent fiber for hosiery end uses called Sideria.

2.3.2. Reaction Spinning

Several commercial spandex fibers were produced by reaction spinning in the 1950s. However, only one producer, Globe Manufacturing Co., currently uses reaction spinning techniques to produce spandex fibers Glospan and its unpigmented counterpart, Cleerspan (13). Reaction-spun fibers include only products 7.7 tex (70 den) or higher; finer Glospan spandex fibers are dry spun.

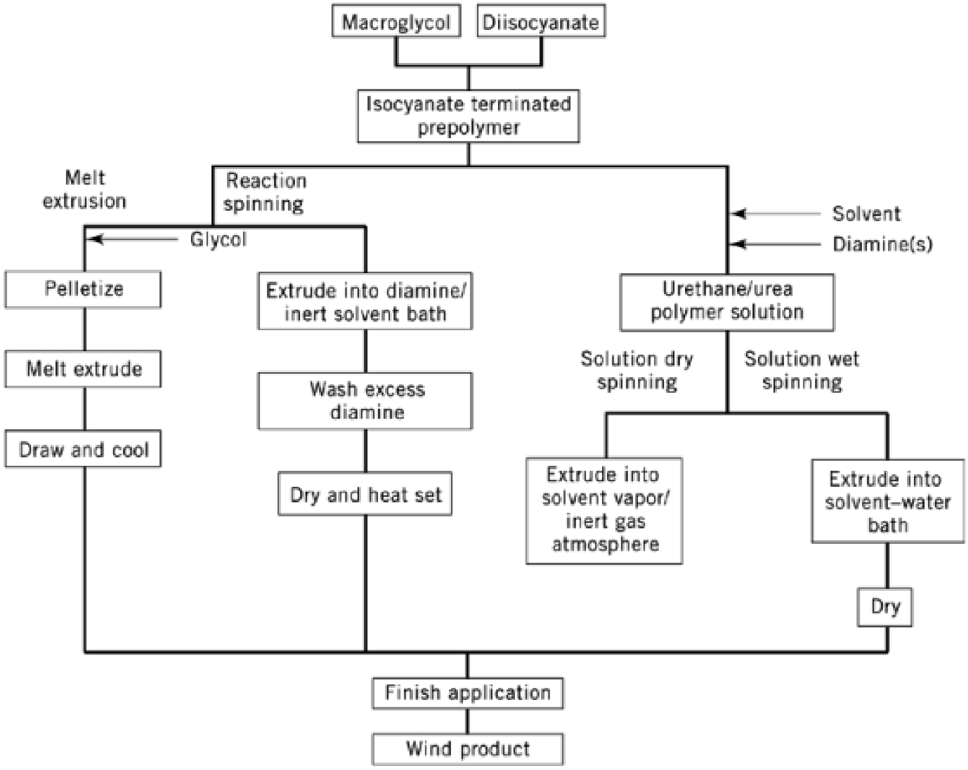


Fig. 4. Spandex fiber production methods.

To produce a spandex fiber by reaction spinning, a 1000–3500 molecular weight polyester or polyether glycol reacts with a diisocyanate at a molar ratio of about 1:2. The viscosity of this isocyanate-terminated prepolymer may be adjusted by adding small amounts of an inert solvent, and then extruded into a coagulating bath that contains a diamine so that filament and polymer formation occur simultaneously. Reactions are completed as the filaments are cured and solvent evaporated on a belt dryer. After application of a finish, the fibers are wound on tubes or bobbins and rewound if necessary to reduce interfiber cohesion.

Trifunctional hydroxy compounds, eg, glycerol [56-81-5] or 2-ethyl-2-(hydroxymethyl)-1,3-propanediol [787-99-6], may be added with the macroglycol to produce covalent cross-links in the reaction-spun spandex fiber. Also, covalent cross-links may result from allophanate and/or biuret formation during curing by reaction of free isocyanate end groups with urethane or urea–NH groups along the polymer chain. A multiplicity of filaments are normally extruded from each spinneret of about 1.1–3.3 tex (10–30 den), then collected in bundles of the desired tex at the exit of the reaction bath. This approach makes the surface area to mass ratio and diamine diffusion into the prepolymer cross-section substantially constant irrespective of the final tex produced, thus minimizing condition changes required in changing tex. Because the individual filaments have reacted incompletely and are in a semiplastic state at the exit of the diamine bath, they interbond quite tightly into a fused multifilament. Production speeds in reaction spinning are limited by filament weakness in the bath along with hydrodynamic drag. Take-up speeds are limited to about 100 m/min.

Stabilizers and pigments are normally slurried with macroglycol and added to the polymeric glycol charge, prior to diisocyanate addition. Therefore, care must be taken to avoid additives that react significantly with diisocyanates or diamines under processing conditions. Also, stabilizers should be chosen that have no adverse catalytic effect on the prepolymer or chain-extension reactions.

Reaction spinning equipment is quite similar to that of solution wet spinning. It differs principally in the use of fewer wash baths and in the use of belt-type dryers instead of heated cans.

2.3.3. Solution Spinning

The initial step to prepare polyurethane polymers for wet or dry solution spinning includes reaction of 1000–3500 molecular weight macroglycol with a diisocyanate at molar ratios of between about 1:1.4 and 1:2.0. Reaction conditions must be carefully selected and controlled to minimize side reactions, eg, allophanate and biuret formation, which can result in trifunctional branched chains and ultimately to insoluble cross-linked polymers. For the prepolymer reaction, poly(tetramethylene ether) glycol [25190-06-1] (PTMEG) and bis(4-isocyanatophenyl) methane [101-68-8] (MDI) are currently the most commonly used macroglycol and diisocyanate. Several types of polyester-based macroglycols are included in spandex producers product lines, but with the exception of Dorlastan, made by Bayer AG in Germany, the polyester-based products represent only a minor part of their spandex fiber production.

In the polymerization reaction, called chain extension, the prepolymer is dissolved in a solvent and reacts with diamine(s) to form a urethane–urea polymer in solution. In all commercial processes, the solvent used is either *N,N*-dimethylformamide [68-12-2] (DMF) or *N,N*-dimethylacetamide [127-19-5] (DMAc). Normally, one or two diamines are used as chain extenders. Because the reaction of diamine with diisocyanate is exceedingly rapid, prepolymer is normally diluted with solvent so that mixing in the polymer reactor is optimized. An improved mixing and chain-extension process has been described whereby the solvent-diluted prepolymer is separated into two groups with chain extension being initiated by reaction of diamine solution with one of these groups, after which the prepolymer of the other group is mixed in and chain extension is completed (14). Molecular weights of polymers made in solution can be controlled by adding small amounts of a secondary monoamine to provide dialkylurea end groups. Branching reactions must be minimized in order to obtain a stable polymer solution for spinning. Stoichiometry of polymerization is normally adjusted to provide a urethane polymer solution of 20–40% solids and viscosity of $20-200\text{Pa·s}$ (200–2000 P). The viscosities and solids of solutions for dry spinning are generally higher than hose used for wet spinning.

Stabilizers, pigments, and other additives are milled in spinning solvent, normally along with small amounts of the urethane polymer to improve dispersion stability; this dispersion is then blended to the desired concentration with polymer solution after chain extension. Most producers combine prepolymerization, chain extension, and additive addition and blending into a single integrated continuous production line.

2.3.4. Dry Spinning

On a worldwide basis, about 90% of all spandex fibers are produced by various adaptations of dry spinning (15, 16). The solution dry spinning process is illustrated in Figure 5. The polymer spinning solution is metered at a constant temperature by a precision gear pump through a spinneret into a cylindrical spinning cell 3–8 m in length. Heated cell gas, made up of solvent vapor and an inert gas, normally nitrogen, is introduced at the top of the cell and passed through a distribution plate behind the spinneret pack. Because both cell gas and cell walls are maintained at high temperatures, solvent evaporates rapidly from the filaments as they travel down the spinning cell. The spinning solvent is then condensed from the cell gases, purified by distillation, and returned for reuse. Individual filament size is normally maintained in the range of 0.6–1.7 tex (5–15 den) to maximize, within operable limits, surface-to-mass ratio and solvent removal rate. Individual filaments are grouped into bundles of the desired final tex at the exit of the spinning cell by a coalescence guide. A commonly used guide employs compressed air to create a minivortex which imparts a false twist and rounded cross section to the filament bundle. Solution dry-spun spandex fibers are normally referred to as continuous multifilaments or

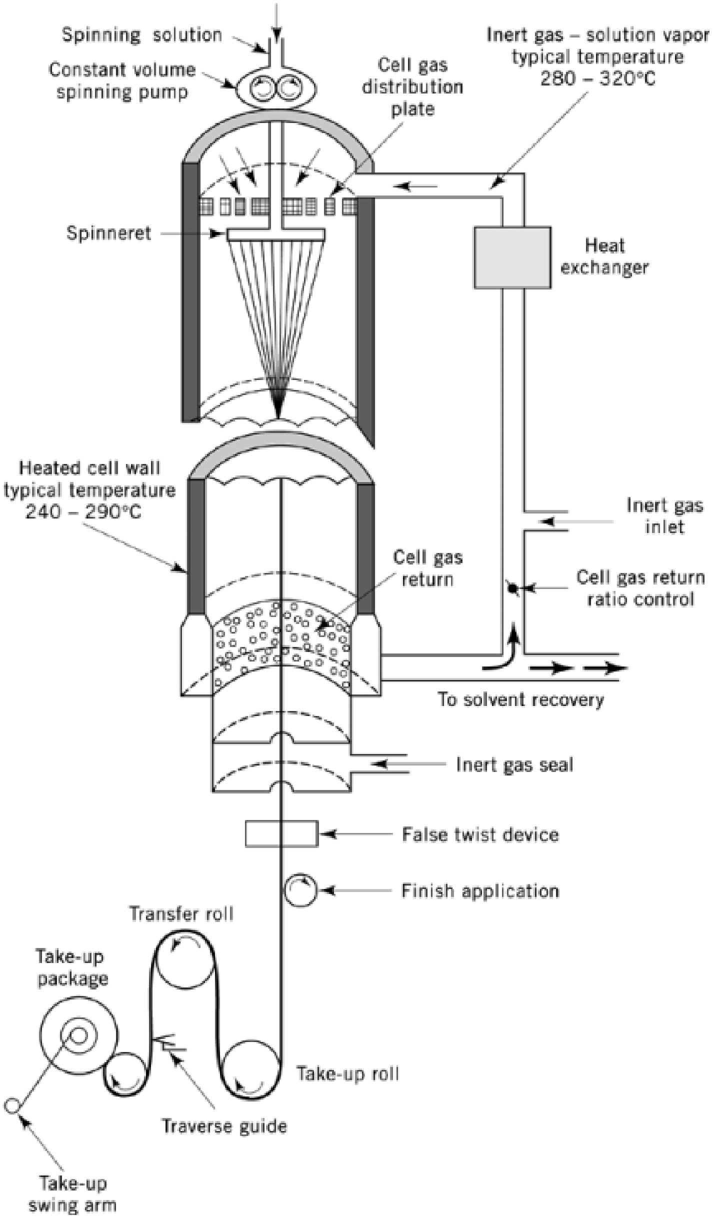


Fig. 5. Spandex production, solution dry spinning process.

coalesced multifilaments. However, the individual filaments do not coalesce into larger structures but remain discrete; they adhere to one another because of natural elastomer tack at their surface.

After coalescence, a finish is applied to the multifilament bundle before it is wound onto a tube. Commonly used finishing agents include poly(dimethyl-siloxane) [9016-00-6] (17) and magnesium stearate [557-04-0] (18) which provide lubrication for textile processing and prevent fibers from sticking together on the package. Windup speeds are in the range of 300–500 m/min depending on tex and producer.

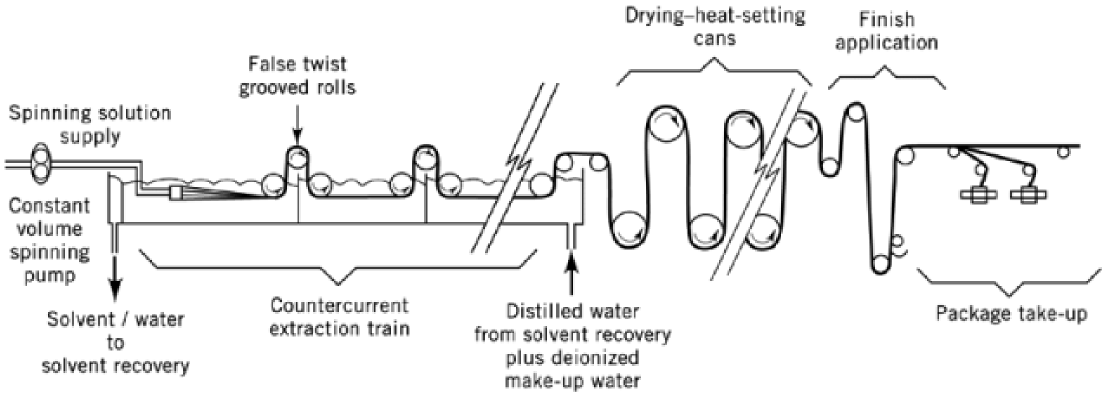


Fig. 6. Spandex production, solution wet spinning process.

2.3.5. Wet Spinning

Any urethane–urea polymer that can be dry spun may also be wet spun; however, the productivity constraints of wet spun processes have limited their utility. A typical wet spinning process line is shown in Figure 6. Spinning solution is pumped by precision gear pumps through spinnerets into a solvent–water coagulation bath. As with dry spinning, individual filament size is maintained at about 0.6–1.7 tex (5–15 den) in order to optimize solvent removal rates. At the exit of the coagulation bath, filaments are collected in bundles of the desired tex. A false twist may be imposed at the bath exit to give the multifilament bundles a more rounded cross section. After the coagulation bath, the multifilament bundles are countercurrently washed in successive extraction baths to remove residual solvent, then dried and heat-relaxed, generally on heated cans. Finally, as in dry spinning, a finish is applied and the multifilaments would on individual tubes. A typical spinning line may produce 100–300 multifilaments at side-by-side filament spacings of less than 5 mm.

Water is continuously added to the last extraction bath and flows countercurrently to filament travel from bath to bath. Maximum solvent concentration of 15–30% is reached in the coagulation bath and maintained constant by continuously removing the solvent–water mixture for solvent recovery. Spinning solvent is generally recovered by a two-stage process in which the excess water is initially removed by distillation followed by transfer of crude solvent to a second column where it is distilled and transferred for reuse in polymer manufacture.

In wet spinning processes, spinning speeds are limited to about 100–150 m/min by hydrodynamic drag of the bath medium. It is this limitation that has apparently caused most spandex fiber producers to have chosen dry spinning techniques. However, this limitation has been minimized by subjecting the spandex filament to drawing as much as three to four times after the spinning bath (19, 20). Temperatures and residence times are selected so that the filaments are brought to temperatures above their second-order transition points, ie, the hard segment melting points. This allows the molecular chains to move freely to relieve stresses and results in filaments of fine tex but with similar mechanical properties as the heavier tex feed. Thus it is possible to windup fibers from a wet spinning process at speeds in excess of 300 m/min by continuously drawing and heat-relaxing the filaments after drying.

3. Chemical Properties

3.1. Stabilization

Both rubber and spandex fibers are subject to oxidative attack by heat, light, atmospheric contaminants such as NO_x, and active chlorine. Rubber is especially subject to oxidative degradation from exposure to ozone whereas urethane polymers are relatively inert. Both rubber and spandex fibers are likely to contain antioxidants; the spandex fibers may also be stabilized to uv light and to atmospheric contaminants that cause discoloration. Spandex fibers use a variety of monomeric and polymeric hindered phenolic-type antioxidants (qv). Many spandex fibers also include uv screeners based on hydroxybenzotriazoles. Several producers include the more recently developed hindered amine-type light stabilizers (21) that apparently act as radical scavengers and therefore also possess antioxidant activity. Compounds with tertiary amine functionality are commonly added to spandex fibers to inhibit discoloration from atmospheric pollutants such as oxides of nitrogen and chemicals that develop under smog-like conditions. Spandex producers have been designing stabilizers that are highly compatible with the segmented urethane polymer to enhance their effectiveness and durability (22–24). Spandex fibers based on polyester soft segments are susceptible to mildew attack in end uses such as swimwear; this type of degradation is minimized by either using antimildew additives or by soft segment structural modifications (25).

3.2. Solvent Resistance

Elastomeric fibers tend to swell in certain organic solvents; rubber fibers swell in hydrocarbon solvents such as hexane. Spandex fibers become highly swollen in chlorinated solvents such as tetrachloroethylene [127-18-4] (Perclene). Although the physical properties of spandex fibers return to normal after the solvent evaporates, considerable amounts of its stabilizers may have been extracted. Therefore, the development of stabilizers that are more resistant to solvent extraction has become important as solvent scouring during mill processing replaces aqueous scouring at many mills, especially in Europe (26).

3.3. Dyeing

Spandex fibers have an affinity for dispersed or acid dyes; rubber fibers normally cannot be dyed. Perfect dye matches between spandex and hard fibers are usually not necessary because the elastomer is well hidden in the fabric. Clear spandex fibers can be left undyed when plied with dyed hard fiber yarns, thus avoiding loss of stretch properties from conditions of dyeing or bleaching. Nylon–spandex combinations are often dyed with disperse dyes, or, for better fastness, with acid dyes (27). Retarders may be needed to prevent the nylon from depleting the acid dye from the bath before the spandex fiber is dyed. With polyester–spandex fabrics, disperse dyes have been used with pressure dyeing or carriers to increase the dyeing rate for the hard fiber (see Dye carriers). However, spandex fibers exhibit relatively poor wetfastness to disperse dyes, and their retractive power can be reduced under pressure dyeing conditions needed for full shades on disperse dyed polyesters. For this reason, many polyester spandex fabrics now contain cationic dyeable polyester in combination with clear (transparent) spandex fiber. Since the spandex fibers have low affinity for cationic dyes, fastness is not a problem, and the fabrics can be dyed at lower temperatures to preserve spandex retractive power (see Dyes, Application and evaluation).

4. Economic Aspects

A worldwide list of spandex fiber and related elastomer producers is shown in Table 2. Most process developments have occurred in the United States, Germany, Japan, and Korea. A large proportion of worldwide capacity is controlled by Du Pont, either directly or through subsidiaries and joint ventures. These include three plants in North America, two in South America, two in Europe, and two in Asia.

Commercially, elastomeric fibers are almost always used in combination with hard fibers such as nylon, polyester, or cotton. Use levels vary from a low of about 3% in some filling stretch cotton fabrics to a high of about 40% in some warp-knit tricot fabrics. Raschel fabrics used in foundation garments normally contain 10–20% spandex fiber.

Prices of spandex fibers are highly dependent on thread size; selling price generally increases as fiber tex decreases. Factors that contribute to the relatively high cost of spandex fibers include (*1*) the relatively high cost of raw materials, (*2*) the small size of the spandex market compared to that of hard fibers which limits scale and thus efficiency of production units, and (*3*) the technical problems associated with stretch fibers that limit productivity rates and conversion efficiencies.

5. Uses

5.1. Cut Rubber and Extruded Latex

The manufacturing technology for cut and extruded rubber thread is much older and more widely known than that for spandex fibers. Because production facilities can be installed with relatively modest capital investment, manufacture of rubber thread is fragmented and more widely distributed with a few major and many minor producers. On a worldwide basis, Fillattice of Italy is the largest rubber thread producer with modern extruded latex plants in Italy, Spain, Malaysia, and the United States. Second in production capacity is the Globe Manufacturing Co., Fall River, Massachusettes with production operations in the United States and the UK. These firms also produce spandex fibers.

Most extruded latex fibers are double covered with hard yarns in order to overcome deficiencies of the bare threads such as abrasiveness, color, low power, and lack of dyeability. During covering, the elastic thread is wrapped under stretch which prevents its return to original length when the stretch force is removed; thus the fiber operates farther on the stress–strain curve to take advantage of its higher elastic power. Covered rubber fibers are commonly found in narrow fabrics, braids, surgical hosiery, and strip lace.

5.2. Spandex Fibers

Spandex fibers are supplied for processing into fabrics in four basic forms as outlined in Table 3. Bare yarns are supplied by the manufacturer on tubes or beams and can be processed on conventional textile equipment with the aid of special feed and tension devices. In covered yarns, the spandex fibers are covered with one or two layers of an inelastic filament or staple yarn; the hard yarn provides strength and rigidity at full extension, which facilitates knitting and weaving.

With core-spun yarns, the spandex fibers are stretched and combined with a roving of inelastic cotton or cotton–polyester staple fibers; twisting action of the hard sheath fibers around the elastomeric fiber core produces a spun yarn that contracts when tension is relieved. Woven fabrics with core-spun yarns generally contain small amounts of spandex fibers; stretch characteristics are the result of the intrinsic properties of the spandex fibers in their final form and to interactions with hard fibers which take place during weaving and heat setting (28). This interaction provides a permanent weave crimp in the hard fiber which together with the spandex component imparts stretch and recovery to the fabric. Coreplied yarns are formed when stretched spandex fibers are plied with extended textured continuous filament yarns on a twisting machine; these yarns are used in high stretch woven fabrics.

Spandex fibers are available as fine as 1.1 tex (10 den), and the finest extruded latex thread available is about 16 tex (140 den). The availability of spandex fibers in such fine sizes and their unique properties

Table 3. Spandex Fiber Uses

Fiber form	Fabric types	Uses
bare	warp knits, circular knits, narrow fabrics (woven, knits, and braids), and hosiery (knit)	foundation garments, swimwear, control tops for pantyhose, brassieres, elastic gloves, waist and leg bands, sportswear, and upholstery
covered	warp knits, circular knits, hosiery (knit), and narrow fabrics	hosiery, elastic bandages, sportswear, upholstery, and sock tops
core-spun	wovens, circular knits, and men's hosiery (knit)	shirting, slacks, and sportswear
core-plied	wovens	blouses and trousers

compared to rubber, eg, dyeability, high modulus, abrasion resistance, and whiteness, has allowed extensive penetration into hosiery and sportswear markets.

BIBLIOGRAPHY

"Spandex" in *ECT* 2nd ed., Vol. 18, pp. 614–633, by R. A. Gregg, Uniroyal, Inc.; "Fibers, Elastomeric" in *ECT* 3rd ed., Vol. 10, pp. 166–181, by T. V. Peters, Consultant.

Cited Publications

1. *Textile Fibers Products Identification Act, U.S. Public Law 85–897*, U.S. Federal Trade Commission, Washington, D.C., effective Mar. 3, 1960.
2. Ger. Pat. 826,641 (1952), E. Windemuth (to Farbenfabriken Bayer).
3. Ger. Pat. 886,766 (1951), W. Brenschede (to Farbenfabriken Bayer).
4. U.S. Pat. 2,957,852 (Oct. 25, 1960), P. Frankenburg and A. Frazer (to Du Pont Co.).
5. U.S. Pat, 2,929,804 (Mar. 22, 1960), W. Steuber (to Du Pont Co.).
6. Jpn. Appl. 63 189132 (1988), I. Matsuya (to Kanebo Ltd.).
7. G. Richeson and J. Spruiell, *J. Appl. Polym. Sci.* **41**, 845 (1990).
8. D. Allport and A. Mohajer, in D. Allport and W. H. Janes, eds., *Block Copolymers*, John Wiley & Sons, Inc., New York, 1973, 443–492.
9. R. Bonart, *Angew. Makromol. Chem.* **58**–**59**(1), 259 (1977).
10. H. Lee, Y. Wang, and S. Cooper, *Macromolecules* **20**, 2089 (1987).
11. Jpn. Pat. Appl. 138, 124 (1975), T. Hidaka, K. Ikawa, and S. Mizutani (to Toray Industries, Inc.).
12. Jpn. Pat. Appl. 63-256719 (1988), S. Tanaka, Y. Yamakawa, and K. Hirasa (to Kanebo Ltd.)
13. U.S. Pat. 3,387,071 (June 4, 1968), J. Cahill, J. Powell, and E. Gartner (to Globe Mfg. Co.).
14. Jpn. Appl. 63 231244 (1988), K. Tani, K. Katsuo, and H. Tagata (to Toyobo Co. Ltd.).
15. H. Ishihara and co-workers, *J. Polym. Eng.* **6**, 237 (1986).
16. T. Kotani and co-workers, *J. Macromol. Sci-Phys.* **831**, 65 (1992).
17. U.S. Pat. 3,296,063 (Jan. 3, 1967), C. Chandler (to Du Pont Co.).
18. U.S. Pat, 3,039,895 (June 19, 1962), J. Yuk (to Du Pont Co.).
19. U.S. Pat, 4,002,711 (Jan. 11, 1977), T. Peters.
20. Jpn. Pat. Appl. 76-04,313 (1976), Y. Ikeda, T. Hirukawa, and Y. Ishiki (to Fuji Spinning Co., Ltd.).
21. H. Miller, *Polymer Preprints, ACS* **25**(1), 21 (1984).
22. Jpn. Pat. Appl. 62-86,047 (1987), H. Hanabatake and A. Kitsuri (to Asahi Chemical Industries).
23. U.S. Pat. 5,028,642 (July 2, 1991), C. Goodrich and W. Evans (to Du Pont Co.).
24. U.S. Pat. 4,824,929 (Ap. 25, 1989), G. Arimatsu and co-workers (to Toyobo Co., Ltd.).
25. Ger. Pat. 3,641,703 (1988), M. Kausch and co-workers (to Farbenfabriken Bayer).
26. Jpn. Pat. Appl. 61-218,659 (1986), (to Asahi Chemical Industries).

27. C. Pernetti, *Tinctoria* **80**, 133 (1983).
28. S. Ibrahim, Ph.D. dissertation, University of Leeds, UK, 1969.

General References

29. A. J. Ultee, in J. I. Kroschwitz ed., *Encyclopedia of Polymer Science and Engineering*, 2nd ed., Vol. **6**, John Wiley & Sons, Inc., New York, 1986, 733–755.
30. M. Couper, in M. Lewin and J. Preston, eds., *High Technology Fibers*, Marcel Dekker, Inc., New York, 1985, 51–85.
31. M. Joseph, *Essentials of Textiles*, 3rd ed., Holt, Rinehard and Wilson, New York, 1984.

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