Fibers Manufacturing:
Synthetic and Cellulosic Fiber Formation Technology

Nylon, polyester, polypropylene and many other polymers are fabricated into filaments and fibers for textile, reinforcement, ropes and a host of other uses. Experts span the different polymer types and the basics of fiber manufacturing: Polymer make up and compound formulation, fiber spinning, fiber quenching and fiber conditioning such as stretching, crimping and coating. Technologists also exist for fiber roll take up, fiber staple production, fiber production from staple and fiber twisting.

Most synthetic and cellulosic manufactured fibers are created by “extrusion” — forcing a thick, viscous liquid (about the consistency of cold honey) through the tiny holes of a device called a spinneret to form continuous filaments of semi-solid polymer.

In their initial state, the fiber-forming polymers are solids and therefore must be first converted into a fluid state for extrusion. This is usually achieved by melting, if the polymers are thermoplastic synthetics (i.e., they soften and melt when heated), or by dissolving them in a suitable solvent if they are non-thermoplastic cellulosics. If they cannot be dissolved or melted directly, they must be chemically treated to form soluble or thermoplastic derivatives. Recent technologies have been developed for some specialty fibers made of polymers that do not melt, dissolve, or form appropriate derivatives. For these materials, the small fluid molecules are mixed and reacted to form the otherwise intractable polymers during the extrusion process (if you are interested in the latest information on extrusion, click here to go to the PolySort chat board on the topic).

The Spinneret
The spinnerets used in the production of most manufactured fibers are similar, in principle, to a bathroom shower head. A spinneret may have from one to several hundred holes. The tiny openings are very sensitive to impurities and corrosion. The liquid feeding them must be carefully filtered (not an easy task with very viscous materials) and, in some cases, the spinneret must be made from very expensive, corrosion-resistant metals. Maintenance is also critical, and spinnerets must be removed and cleaned on a regular basis to prevent clogging.

As the filaments emerge from the holes in the spinneret, the liquid polymer is converted first to a rubbery state and then solidified. This process of extrusion and solidification of endless filaments is called spinning, not to be confused with the textile operation of the same name,
where short pieces of staple fiber are twisted into yarn. There are four methods of spinning filaments of manufactured fibers: wet, dry, melt, and gel spinning.

**Wet Spinning**
Wet spinning is the oldest process. It is used for fiber-forming substances that have been dissolved in a solvent. The spinnerets are submerged in a chemical bath and as the filaments emerge they precipitate from solution and solidify.

Because the solution is extruded directly into the precipitating liquid, this process for making fibers is called wet spinning. Acrylic, rayon, aramid, modacrylic and spandex can be produced by this process.

**Dry Spinning**
Dry spinning is also used for fiber-forming substances in solution. However, instead of precipitating the polymer by dilution or chemical reaction, solidification is achieved by evaporating the solvent in a stream of air or inert gas.

The filaments do not come in contact with a precipitating liquid, eliminating the need for drying and easing solvent recovery. This process may be used for the production of acetate, triacetate, acrylic, modacrylic, PBI, spandex, and vinyon.

**Melt Spinning**
In melt spinning, the fiber-forming substance is melted for extrusion through the spinneret and then directly solidified by cooling. Nylon, olefin, polyester, saran and sulfur are produced in this manner.
Melt spun fibers can be extruded from the spinneret in different cross-sectional shapes (round, trilobal, pentagonal, octagonal, and others). Trilobal-shaped fibers reflect more light and give an attractive sparkle to textiles.

Pentagonal-shaped and hollow fibers, when used in carpet, show less soil and dirt. Octagonal-shaped fibers offer glitter-free effects. Hollow fibers trap air, creating insulation and provide loft characteristics equal to, or better than, down.

**Detailed production flowcharts:**
- Acrylic
- Nylon (Polyamide)
- Polyester

**Gel**
Gel spinning is a special process used to obtain high strength or other special fiber properties. The polymer is not in a true liquid state during extrusion. Not completely separated, as they would be in a true solution, the polymer chains are bound together at various points in liquid crystal form. This produces strong inter-chain forces in the resulting filaments that can significantly increase the tensile strength of the fibers. In addition, the liquid crystals are aligned along the fiber axis by the shear forces during extrusion. The filaments emerge with an unusually high degree of orientation relative to each other, further enhancing strength. The process can also be described as dry-wet spinning, since the filaments first pass through air and then are cooled further in a liquid bath. Some high-strength polyethylene and aramid fibers are produced by gel spinning.

**Stretching and Orientation**
While extruded fibers are solidifying, or in some cases even after they have hardened, the filaments may be drawn to impart strength. Drawing pulls the molecular chains together and orients them along the fiber axis, creating a considerably stronger yarn.
Nylon Fiber  
(Polyamide)
Microfiber

One of the most important developments in recent years has been the technology to extrude extremely fine filaments (less than 1.0 denier) while maintaining all of the strength, uniformity and processing characteristics expected by textile manufacturers and consumers. These “microfibers” are even finer than luxury natural fibers, such as silk [#1]. This comparison, coupled with their exceptional performance, has led some in the industry to refer to microfibers as “supernatural”. They live up to that name.

In many product lines, it is the luxurious feel and look of the fabrics which makes microfibers so special. In others, it is this unique physical and mechanical performance.

Consider, for example, the advantages of polyester microfiber when used in outerwear. A raincoat or jacket made from 100% microfiber will be much lighter and more comfortable than one made from conventional fibers. [#2] Since the small filaments pack closely together, they provide a wind barrier to prevent loss of body heat and assuring comfort on chilly days. This close packing of fibers, together with polyesters' natural resistance to wetting also gives the fabric the ability to repel rain. [#4] The non-wetting surface of the fibers causes water to form beads (like rain on a newly-waxed car). These beads are much larger than the spaces between the yarns and water is effectively locked out. And this is done without the need for chemical treatments or coatings which can make the fabric heavier and less able to "breathe". Fabrics from microfibers, on the other hand, breathe well. [#3] Although the spaces between the yarns are too small to be penetrated by liquid water, they are ample for the passage of moisture vapor, leaving the
wearer dry and comfortable.

This is only one example. Microfiber yarns are now available for most major generic fibers. They can bring their outstanding performance to a wide variety of end uses.
Bicomponent Fiber

**Definition:** Bicomponent fiber is comprised of two polymers of different chemical and/or physical properties extruded from the same spinneret with both polymers within the same filament.

**Bicomponent Fiber Capabilities**
Bicomponents can provide:

- Thermal bonding
- Self bulking
- Very fine fibers
- Unique cross sections
- The functionality of special polymers or additives at reduced cost

**Common Bicomponent Configurations**
Most commercially available bicomponent fibers are configured in a sheath/core, side-by-side, or eccentric sheath/core arrangement.

![Sheath/Core](image1)
![Side by Side](image2)
![Eccentric Sheath/Core](image3)

**Advantages of Bicomponent Thermal Binder Fibers**

- Uniform distribution of adhesive
- Fiber remains a part of structure and adds integrity
- Customized sheath materials to bond various materials
- Wide range of bonding temperatures
- Cleaner, environmentally friendly (*no effluent*)
- Recyclable
- Lamination/molding/densification of composites.

**Common Polymer Combinations in Bicomponent Thermal Binder Fibers**

- Polyester Core *(250°C melt point)* with Copolyester Sheath *(melt points of 110°C to 220°C)*
- Polyester Core *(250°C melt point)* with Polyethylene Sheath *(130°C melt point)*
- Polypropylene Core *(175°C melt point)* with Polyethylene Sheath *(130°C melt point)*

**Self Bulking Bicomponent Fibers**

- Created most often with side-by-side or eccentric cross section
- Variation in orientation across the fiber causes crimping due to differential shrinkage or strain with applied heat or relaxation.
High - Performance Fibers

Specialty fibers are engineered for specific uses that require exceptional strength, heat resistance and/or chemical resistance. They are generally niche products, but some are produced in large quantities.

Glass is the oldest, and most familiar, performance fiber. Fibers have been manufactured from glass since the 1930s. Although early versions were strong, they were relatively inflexible and not suitable for many textile applications. Today's glass fibers offer a much wider range of properties and can be found in a wide range of end uses, such as insulation batting, fire resistant fabrics, and reinforcing materials for plastic composites. Items such as bathtub enclosures and boats, often referred to as “fiberglass” are, in reality, plastics (often crosslinked polyesters) with glass fiber reinforcement. And, of course, continuous filaments of optical quality glass have revolutionized the communications industry in recent years.

Carbon fiber may also be engineered for strength. Carbon fiber variants differ in flexibility, electrical conductivity, thermal and chemical resistance. Altering the production method allows carbon fiber to be made with the stiffness and high strength needed for reinforcement of plastic composites, or the softness and flexibility necessary for conversion into textile materials. The primary factors governing the physical properties are degree of carbonization (carbon content, usually greater than 92% by weight) and orientation of the layered carbon planes. Fibers are produced commercially with a wide range of crystalline and amorphous contents.

Because carbon cannot readily be shaped into fiber form, commercial carbon fibers are made by extrusion of some precursor material into filaments, followed by a carbonization process to convert the filaments into carbon. Different precursors and carbonization processes are used, depending on the desired product properties. Precursor fibers can be specially purified rayon (used in fabrication of the space shuttle), pitch (for reinforcement and other applications) or acrylics (for varied end uses). Since carbon fiber may be difficult to process, the precursor fiber may be converted into fabric form, which is then carbonized to produce the end product. The following materials are common precursors for carbon fiber:

Rayon, in either fiber or fabric form, is one of the most common precursors for carbon fiber. Specially purified rayon containing a dehydration catalyst (frequently a phosphorus compound) is subjected to heat treatment to dehydrate the cellulose structure. Higher temperature treatment and controlled oxidation produces carbonization. A third, higher temperature, treatment may also be used to further increase the carbon content. Many aerospace applications use rayon fabric to produce material with high thermal resistance but relatively low strength.

Acrylic fiber (based on polyacrylonitrile, or PAN) can also serve as a carbon precursor. The carbonization process is similar to that used for rayon, except that continuous tension is applied to produce a more highly oriented ladder structure and, thus, a fiber with greater tensile strength. Carbon fiber produced from PAN is most frequently used as reinforcement for a wide variety of plastic composites.

Pitch, a polyaromatic hydrocarbon material derived from petroleum or coal, is another common carbon fiber precursor. The pitch is converted into a liquid-crystal state prior to extrusion into fiber form. The shear forces during extrusion and subsequent drawing produce a filament with high molecular orientation in the direction of the fiber axis. This orientation is maintained during oxidation and high temperature carbonization. Carbon fiber can be produced in this way with a variety of strength and flexibility characteristics.
Aramids are among the best known of the high-performance, synthetic, organic fibers. Closely related to the nylon, aramids are polyamides derived from aromatic acids and amines. Because of the stability of the aromatic rings and the added strength of the amide linkages, due to conjugation with the aromatic structures, aramids exhibit higher tensile strength and thermal resistance than the aliphatic polyamides (nylons). The para-aramids, based on terephthalic acid and p-phenylene diamine, or p-aminobenzoic acid, exhibit higher strength and thermal resistance than those with the linkages in meta positions on the benzene rings. The greater degree of conjugation and more linear geometry of the para linkages, combined with the greater chain orientation derived from this linearity, are primarily responsible for the increased strength. The high impact resistance of the para-aramids makes them popular for “bullet-proof” body armor. For many less demanding applications, aramids may be blended with other fibers.

PBI (polybenzimidazole) is another fiber that takes advantage of the high stability of conjugated aromatic structures to produce high thermal resistance. The ladder-like structure of the polymer further increases the thermal stability. PBI is noted for its high cost, due both to high raw material costs and a demanding manufacturing process. The high degree of conjugation in the polymer structure imparts an orange color that cannot be removed by bleaching. When converted into fabric, it yields a soft hand with good moisture regain. PBI may be blended with aramid or other fibers to reduce cost and increase fabric strength.

PBO (polyphenylenebenzobisozazole) and PI (polyimide) are two other high-temperature fibers based on repeating aromatic structures. Both are recent additions to the market. PBO exhibits very good tensile strength and high modulus, which are useful in reinforcing applications. Polyimide's temperature resistance and irregular cross-section make it a good candidate for hot gas filtration applications.

Sulfar (PPS, polyphenylene sulfide) exhibits moderate thermal stability but excellent chemical and fire resistance. It is used in a variety of filtration and other industrial applications.

Melamine fiber is primarily known for its inherent thermal resistance and outstanding heat blocking capability in direct flame applications. This high stability is due to the crosslinked nature of the polymer and the low thermal conductivity of melamine resin. In comparison to other performance fibers, melamine fiber offers an excellent value for products designed for direct flame contact and elevated temperature exposures. Moreover, the dielectric properties and cross section shape and distribution make it ideal for high temperature filtration applications. It is sometimes blended with aramid or other performance fibers to increase final fabric strength.

Fluoropolymer (PTFE, polytetrafluoroethylene) offers extremely high chemical resistance, coupled with good thermal stability. It also has an extremely low coefficient of friction, which can be either an advantage or disadvantage, depending on the use.

HDPE (high-density polyethylene) can be extruded using special technology to produce very high molecular orientation. The resulting fiber combines high strength, chemical resistance and good wear properties with light weight, making it highly desirable for applications ranging from cut-proof protective gear to marine ropes. Since it is lighter than water, ropes made of HDPE float. Its primary drawback is its low softening and melting temperature.