TEXTILE FIBERS

COTTON INCORPORATED

Textile Fibers

1 INTRODUCTION

A textile **fiber** is defined, in a very general way, as any product capable of being processed in weaving, knitting, or non-conventional systems into a fabric substrate. It may be thought of as the smallest visible unit of textile production.

In more practical terms, a fiber is a material with the following characteristics:

- high length-to-diameter ratio (at least 1000 to 1)
- small diameter (10 to 200 microns, or 0.0005 to 0.01 inches)
- low bending rigidity
- white or clear color

For use as textile material, the fiber must also have the following properties to at least some degree:

- strength
- extensibility
- temperature resistance
- chemical resistance

Textile end uses require a wide variety of fiber properties. All textile fibers share many of these properties, but not many fibers have all of these properties.

2 CLASSIFICATION OF TEXTILE FIBERS

Fibers are classified by their chemical origin, falling into two groups or families: **natural** fibers and **manufactured** fibers. Manufactured fibers are also referred to as **manmade** or **synthetic** fibers. The classification system used in the United States is dictated by the Textile Fiber Products Identification Act (TFPIA). Figure 1 gives a breakdown of textile fibers by these groupings, and the Appendix compares the properties of some of the most commonly used fibers.

2.1 Natural Fibers

Natural fibers are those that occur in fiber form in nature. Traditionally, natural fiber sources are broken down into **animal**, **plant**, or **mineral**. Fibers from plant or vegetable sources are more properly referred to as **cellulose**-based and can be further classified by plant source. They may be separated from the plant stalk, stem, leaf, or seed. Fibers from animal sources are more properly known as **protein**-based fibers. They are harvested from an animal or removed from a cocoon or web. **Mineral** fibers are those that are mined from the earth. Except for silk, all natural cellulose- and protein-based fibers are obtained in short lengths and are called **staple** fibers. Silk is a **continuous filament** fiber.

2.1.1 Cellulose-Based Fibers

Cellulose-based fibers consist of **bast**, **leaf**, and **seed-hair** fibers. Bast fibers come from the stem of the plant and include flax, hemp, jute, and ramie. Leaf fibers are stripped from the leaves of the plant and include manila and sisal. Seed-hair fibers are collected from seeds or seed cases and include cotton and kapok.

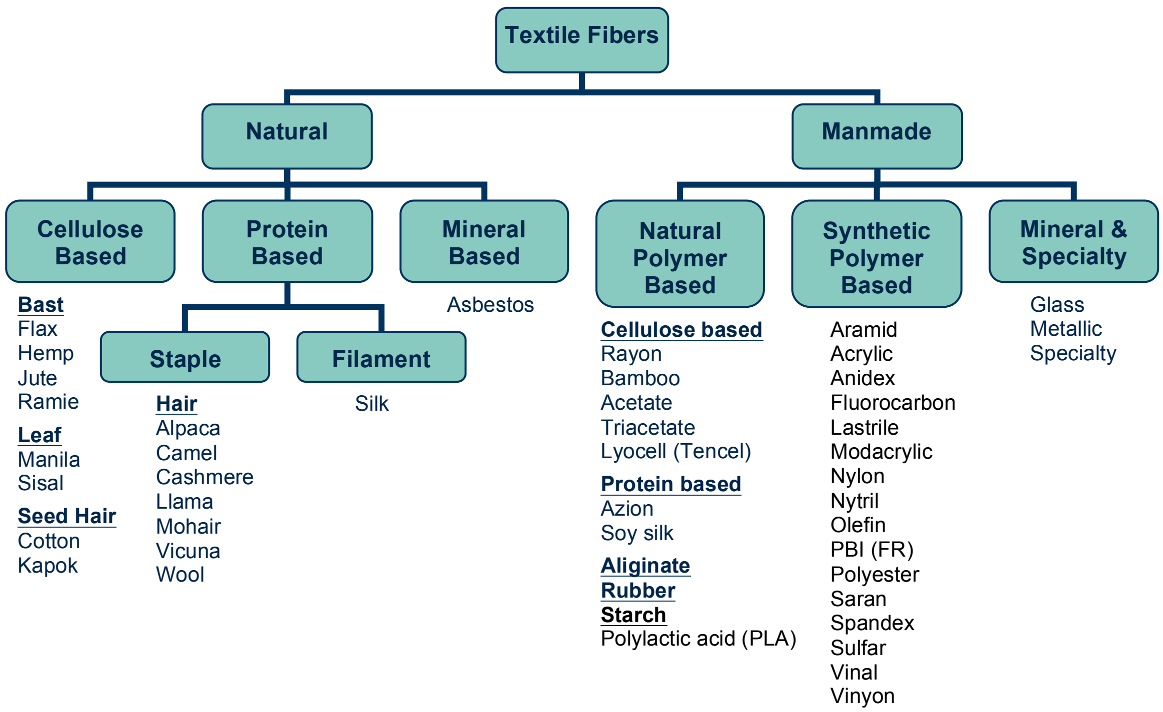

Figure 1. Textile fiber classification

Cotton, obtained from the cotton seed, is the best-known and most-used natural cellulosic fiber. Cotton fiber is discussed in detail in Section 3 of this document.

Flax is the bast fiber of the flax plant, used to make linen fabric. The plants are cultivated and grown in such a way as to produce long, thin stems. The plant is pulled from the ground for processing. The non-fibrous material in the stem is rotted away in a process called “retting.” Once retting is complete, the fibrous mass is rinsed and dried. The fiber is separated from the woody portion of the decomposed material by breaking and “scutching” (scraping). “Hackling” refers to combing the scutched fibers to separate the long and short fibers. The fiber is then spun, and S-twist is inserted, to produce linen thread.

Hemp is a coarse, durable bast fiber from the plant *Cannabis sativa.* It is processed into a usable fiber in the same way as flax. It is used primarily for industrial and commercial textiles, especially cords, twine, and rope.

Jute is a bast fiber from the stem of plants in the genus *Corchorus*, processed in the same way as flax. It widely used for industrial end uses such as sacking, burlap, twine, and backing for tufted carpets.

Kapok is from the seed pods of the Java kapok tree *(Ceiba pentandra).* The seed pod is similar to the cotton boll; however, the dried fibers are easily shaken off the seed. A buoyant fiber, kapok is used primarily in life jackets, as special stuffing for pillows, and in some mattresses. It is not spun into yarn.

Manila is from the leaf stalks of the abacá plant *(Musa textilis).* The fibers are separated from the fleshy part of the leaf stalk. Manila is generally used in rope and cordage.

Ramie is a bast fiber from the stalk of the ramie plant *(Boehmeria nivea),* also known as "China grass." The plant is a perennial shrub that can be cut several times a year once mature. The cut plant's stalks are peeled or retted to remove the outer woody covering, revealing the fine fibers underneath. Degumming removes pectins and waxes, followed by bleaching, neutralizing, washing, and drying. The fiber is similar to flax, but more brittle. Ramie can be spun alone or with other fibers, especially cotton.

Sisal is from the leaves of plant *Agave sisalana.* The leaves are cut when the plant is about four years old, and the fibers are separated from the fleshy part of the leaf. Sisal has industrial uses, most commonly as a rug or carpet backing.

2.1.2 Protein-Based Fibers

Protein-based fibers are from animal sources, most commonly the hair of the animal. Animal-hair fibers are **long-staple fibers**, ranging in length from 2.5 to 10 inches or more. Silk is a natural protein fiber extruded by the silk worm. With a length of over 500 yards, it is classified as a **filament fiber**.

Wool is a fine hair fiber from sheep. In labeling, the term "wool" also may be used to identify fibers from other fleece animals, such as the Angora goat, Cashmere goat, camel, alpaca, llama, and vicuña. Sheep-wool fiber can be sheared from the living animal or pulled from the hide after slaughtering. Sheared or clipped wool is superior to pulled wool. Sheep normally are sheared only once a year. Lamb's wool is wool from sheep under 8 months of age. "Virgin wool" (or "new wool") comes from the first shearing of the animal and is most highly prized. (The term "virgin wool" is also used to mean wool that has never previously been processed.)

Alpaca is the long, fine hair fiber from the alpaca, which is a relative of the camel native to South America. It is shorn from the animal once every two years. The soft, fine undercoat is used in textiles.

Angora is the long, fine hair fiber from the Angora rabbit. It is not to be confused with the hair fiber of the Angora goat, the source of mohair. Angora rabbits are raised domestically. The fur is combed and clipped from the rabbit every three months.

Camel hair comes from the Bactrian camel. The fiber is shed, and about 5 pounds (2.7 kilograms) is produced per camel. The underhairs are used in textiles, and the coarse outer guard hairs are used in paint brushes and other non-apparel uses.

Cashmere is the soft hair fiber from the cashmere (kashmir) goat. The fiber is harvested by combing the animal. A single goat produces only about 4 ounces (114 grams) of fiber a year. Cashmere is considered a luxury fiber.

Llama hair fibers are shorn from the animal once a year. They are similar to alpaca fibers, but weaker.

Mohair is the long, straight, fine hair fiber from the Angora goat. The fiber is usually sheared from the animal twice a year.

Vicuña is the hair fiber from a small non-domesticated llama-like animal about the size of a dog. The animal lives at elevations above 16,000 feet in South America and has been listed as endangered since 1969. Vicuña is the softest of the fleece fibers.

Silk is a natural protein secreted by the larvae of several moth species. The larvae use the filaments to construct a cocoon, from which the silk is extracted. Twin filaments of the protein fibroin are secreted and bound together in a single strand with the protein gum sericin. During processing, the sericin is removed, leaving the fibroin protein. **Cultivated** or **cultured silk** is produced in very controlled conditions of environment and diet. **Tussah** or **wild silk** is harvested from natural sources.

2.1.3 Mineral-Based Fibers

Mineral-based fibers are mined from the earth. Asbestos is by far the most common mineral-based fiber. Asbestos is not used today for general apparel or home furnishings, because exposure to asbestos poses serious health risks. However, it is still used in some heavy industrial and aerospace applications, because it is completely nonflammable.

2.2 Manmade Fibers

Manmade fibers, such as nylon, polyester, and rayon, are produced by chemical reactions controlled by people, rather than occurring naturally. The term **synthetic fibers** is often used to designate manmade fibers; however, to many people, this term has a negative connotation, meaning inauthentic, artificial, or fake. TFPIA classifies manmade or **manufactured fibers** by **generic names**. Currently, TFPIA recognizes 26 generic groups of manmade fibers. Three conditions must be met before a new generic group is established:

- The chemical composition must be radically different from those on the list, and that chemical constitution must produce significantly different physical properties.
- A new proposed classification must have importance to the majority of consumers and not just to a small group of professionals.
- The fiber must be in active commercial development.

Manmade fibers are identified as being made from a natural polymer base, made from a synthetic polymer base, or mineral- or specialty-based.

2.2.1 Natural-Polymer-Based Fibers

Natural-polymer-based fibers include cellulose-based, protein-based, alginate, rubber, and starch fibers.

Cellulose-based fibers include rayon, acetate, triacetate, and lyocell. **Rayon** is a manufactured fiber composed of regenerated cellulose. Regenerated cellulose is a fiber in which substituents have replaced not more than 15% of the hydrogens of the hydroxyl groups of the original cellulosic material. Common sources of rayon raw cellulose material are cotton, wood pulp, various grasses, and, recently, bamboo. Rayon is produced by three methods: the viscose, cuprammonium, and solvent-spun (lyocell) processes.

Viscose rayon is produced by dissolving cellulose xanthate into sodium hydroxide. The xanthate solution is extruded into an acid bath, where the pure cellulose is regenerated and coagulated into filament form.

Cuprammonium rayon fibers are formed by precipitation of cellulose dissolved in a solution of copper oxide and ammonia.

Solvent-spun rayon is formed by dissolving wood pulp in amine oxide. This newer process is considered more environmentally friendly then the other methods, because 99% of the solvent is reclaimed. The patents on this process are owned by Lenzing, and the fiber generic name is lyocell.

Acetate fibers are manufactured fibers in which the fiber-forming substance is cellulose acetate. Where at least 92% of the hydroxyl groups are acetylated, the term **triacetate** may be used as a generic description of the fiber.

2.2.2 Synthetic-Polymer-Based Fibers

Synthetic-polymer-based fibers are those made from chemical polymers not found in nature. These fibers are mainly insoluble and are not chemically reactive. The most common synthetic-polymer-based fibers are acrylics, aramids, modacrylics, nylon, olefins, polyester, and spandex.

Acrylic is a manufactured fiber formed from any long-chain synthetic polymer composed of at least 85% acrylonitrile units by weight. The goal in developing acrylic was to have a fiber to compete with wool in staple form and silk in filament form. Currently, only staple acrylic fibers are produced. The specific gravity is low (1.17), resulting in a soft but not bulky hand. Acrylics also have excellent resistance to sunlight; long exposures do not affect their strength or color. The most common uses for acrylics today are socks, knit sweaters, tenting, awnings, and loungewear.

Aramid is a manufactured fiber formed from a long-chain synthetic polyamide in which at least 85% of the amide linkages are attached directly to two aromatic rings. The spinning system is a solvent process, of which there are variations. Aramid fibers offer a high level of performance. The best-known aramids are Nomex and Kevlar. Nomex is similar to nylon in strength, but is flame retardant. Kevlar is extremely strong. Both fibers are coarser than other synthetics and are extremely hard to dye.

Modacrylic is a manufactured fiber formed from any long-chain synthetic polymer consisting of less than 85% but at least 35% acrylonitrile units (except fibers qualifying as rubber or anidex, an elastomeric fiber like spandex). Like acrylics, modacrylics have excellent resistence to sunlight. Modacrylics are by their chemical nature flame retardant, being hard to ignite and self-extinguishing.

Nylon is a manufactured fiber formed from a long-chain synthetic polyamide in which at least 85% of the amide linkages are attached directly to two aromatic rings. Nylon is melt-spun and is produced in a variety of cross-sectional shapes. Nylon comes in several types, produced by different reaction processes. The most common types are nylon 6 and nylon 6,6. Nylon is used in almost every textile application.

Olefin is a manufactured fiber formed from any long-chain synthetic polymer consisting of at least 85% ethylene, propylene, or other olefin units (except amorphous [noncrystalline] polyolefins qualifying as rubber). Olefins consist only of carbon and hydrogen atoms, and their cross-sectional shape can vary. The two major olefins are polyethylene and polypropylene, which have good strength (with polypropylene the stronger). Olefins are extremely sensitive to heat. They can shrink excessively at temperatures as low as 212°F (100°C), which limits their use with other fibers that are processed in dyeing and finishing at temperatures above 212°F. Also, fabrics made of olefin are very difficult to iron. Olefins have essentially no moisture regain or absorption, which is a benefit for rainwear uses, but makes the products uncomfortable to wear in humid conditions. Olefins are important to the industrial markets, with applications in carpets, carpet backing, fiber bale coverings, bags, agricultural end uses, and ropes, among many others.

Polyester is a manufactured fiber formed from any long-chain synthetic polymer consisting of at least 85% the ester of a substituted aromatic carboxylic acid, including (but not limited to) substituted terephthalate units and *para*-substituted hydroxybenzoate units. Polyester comes in numerous types, depending on the chemistry used in production. All polyesters are inert. They offer a wide range of performance features, but because they are inert, they are not easily modified. Polyesters are oleophilic (having a strong affinity for oils) and therefore must be treated with a soil-release chemistry to prevent soiling and body-odor retention. Along with nylon, polyester is important in apparel, home, commercial, and industrial markets.

Rubber fibers are manufactured fibers formed from natural or synthetic rubber. Charles Goodyear discovered the process for vulcanizing rubber, which allowed the fiber to be extruded into shapes, including a textile fiber. Natural rubber from rubber trees and synthetic rubber are classified the same, and no distinction is made on care labels.

Spandex fibers are manufactured fibers formed from a long-chain synthetic polymer consisting of at least 85% segmented polyurethane. Spandex fibers are elastomeric fibers, which are stretchy and rubber-like substances. They have extremely high elongation, at least 200% and in some cases up to 800%. Rubber and spandex are the best-known elastomeric fibers. Spandex is a segmented block polymer and has several cross-sectional shapes, of which the most common is a “dog bone” shape. The extrusion process results in some fusing of adjacent filaments to produce a coalesced filament yarn. Spandex fibers are very weak; however, the high degree of stretch allows for uses where the lack of strength is overcome. In apparel products, spandex is almost always used only in small amounts with other fibers to provide a desired degree of stretch.

2.2.3 Manmade Mineral-Based and Specialty Fibers

Manmade mineral-based and specialty fibers include special-use fibers such as glass fibers and metallic fibers.

Fiberglass is a generic term used to identify manufactured fibers formed from molten silica glass; the name Fiber-glas is a registered trademark. Glass fibers have high strength but very low elongation. Their tactile properties are unpleasant, because the cut ends of the glass fibers cause tiny cuts in the skin. These properties prevent fiberglass from being used for apparel. However, fiberglass has very important industrial applications and is used to some extent for home-textile products, such as draperies.

2.2.4 Manmade Fiber Formation

Regardless of how manmade polymers are produced, similar methods are used to form them into fibers. The basic process for forming polymer fibers (referred to as **spinning**) is to convert the polymer to a fluid state and force (extrude) it through the tiny holes of a **spinnerette**, forming long, slender filaments. Figure 2 shows a typical spinnerette. The spinning process used depends on the type of polymer. Systems currently in use include melt spinning, wet spinning, dry spinning, emulsion spinning, and gel spinning. The filaments are then stretched or drawn to further reduce their thickness and increase their strength (by increasing their orientation along the fiber axis). The filaments are collected for further processing.

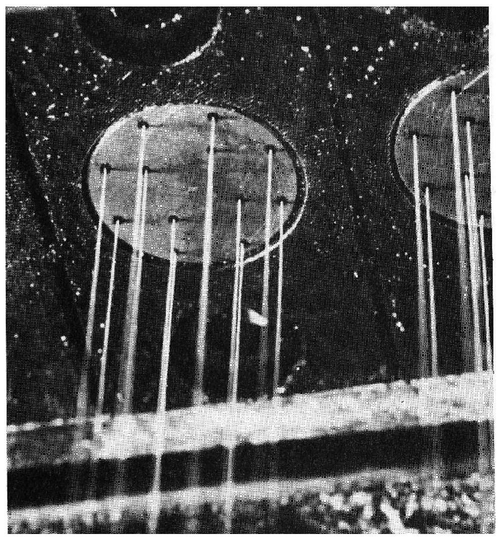

Figure 2. Manmade-fiber spinnerette

Polymer fibers can be processed and used as single-strand **monofilament fibers** or, more commonly, as **multifilament yarns**, consisting of two or more filaments twisted together or formed through the use of more than one spinnerette. Multifilament yarns are designated by the overall yarn size, number of filaments, and size of each filament. For example, polyester yarn consisting of 34 filaments, each 1.5 denier, with an overall overall yarn size of 150 denier would be designated as 150/34/1.5 denier polyester.

Filament yarn may be textured or untextured. In untextured yarns, the filaments are tightly packed, parallel, and straight, resulting in little bulk or stretch. In textured yarns, the filaments are kinked or crimped, expanding the filament structure and giving the yarn more volume. Texturizing shortens the yarn, increasing bulk and stretch. The most common methods of texturizing the filaments are air entanglement, gear crimping, stuffer-box crimping, knife-edge texturizing, and knit-de-knit crimping. Figure 3 shows longitudinal views of textured and untextured filaments.

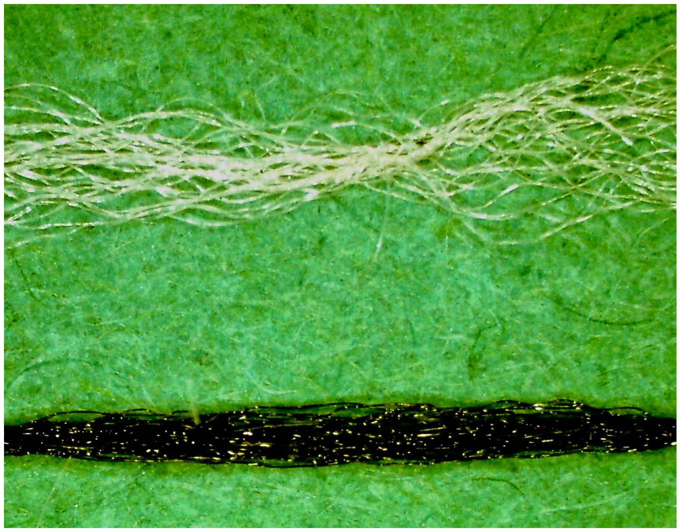

Figure 3. Longitudinal views of textured (top) and untextured (bottom) manmade filaments

2.2.5 Manmade Fiber Length

Manmade fibers are also classified by length as **staple fibers** and **filament fibers**. Staple fibers are filaments cut to short lengths (measured in inches or centimeters). Filament fibers are long and not easily measured.

If a manmade fiber is to be cut into staple fibers for spinning on the short-staple (cotton) or long-staple (worsted) spinning systems, then many filaments are grouped into a **tow**, which is cut into the desired fiber lengths. For better fiber-to-fiber cohesion in staple spinning, the filaments are crimped before being cut, with many crimps per inch.

2.2.6 Manmade Fiber Cross-Sectional Shape

The holes in the spinnerettes can be milled or formed into various shapes, resulting in manmade fibers with a variety of cross-sectional shapes. The most common shapes are round, dogbone, trilobal, serrated, and square with voids (holes). Other "designer" shapes may also be used. The different shapes result in different degrees of luster, texture, friction, and, in some cases, moisture wicking. Figure 4 shows examples of cross-sectional shapes of manmade fibers.

2.2.7 Manmade Fiber Modifications

The most common modifications in the manufacture of manmade fibers are changes that affect luster, color, and size, as well as the use of two different polymers to form a fiber.

In their purest form, filament fibers are very bright. For some end uses, this might be desired. However, for most end uses, the fibers are delustered to some degree by the addition of titanium dioxide (TiO_2) to the spinning solution. TiO_2 reduces the fiber's reflection of light; the more TiO_2 added, the duller the fiber. Levels of luster may be referred to as "over-bright," "bright," "semi-dull," and "dull."

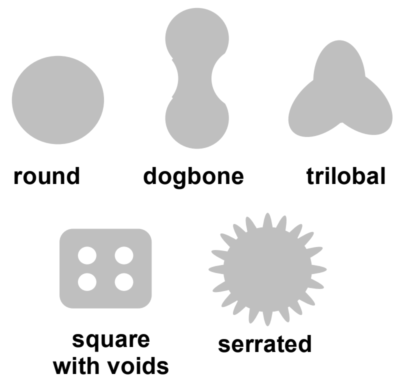

Figure 4. Cross-sectional shapes of manmade fibers

Almost all manmade fibers can be dyed by addition of color to the polymer to be spun, a method called **solution** or **dope dyeing**. With some manmade fibers, including spandex, polypropylene, and olefins, good color fastness can be achieved only by this method.

In recent years, there has been a trend towards **microdenier** filament size. Any manmade fiber can be spun in various deniers. A fiber or filament with a size of 1.0 denier or less is considered to be a microdenier fiber. "Microdenier" is not a generic or licensed fiber name; it simply refers to fiber size.

A **bicomponent fiber** consists of two polymers that differ chemically and/or physically. Both polymers are spun separately on the same spinnerette and combined into one filament. For example, two polymers may be spun side by side or concentrically (as a sheath around a core), or one polymer may be suspended as droplets within the other.

3 COTTON FIBER

Cotton is a natural fiber (**vegetable fiber**) obtained from the seed of the cotton plant. Chemically, cotton is a polysaccharide or polymeric sugar that is represented by the chemical formula $(C_6H_{10}O_5)_n$.

For most apparel and home end uses, cotton fiber is particularly well suited because of its combination of strength, durability, and comfort properties. Cotton also has good temperature resistance, which is important in textile-mill dyeing and finishing processes and consumer care.

3.1 Cultivation of Cotton

Cotton is a plant of the genus *Gossypium,* which includes 32 species, several of which produce cotton fibers. The cottons native to Asia are primarily *G. arboreum* and *G. herbaceum,* and U.S. cottons are principally *G. barbadense* and *G. hirsutum*. *G. barbadense* includes the long-staple Pima, Egyptian, and Sea Island cotton varieties, and *G. hirsutum* is upland cotton. Today, American upland cotton is grown around the world.

Cotton is grown throughout the southern United States. The varieties grown vary somewhat by region. Cotton grown in the Southeast relies mainly on rainwater, while cotton grown in the West typically is irrigated. Figure 5 shows the states where cotton is grown.

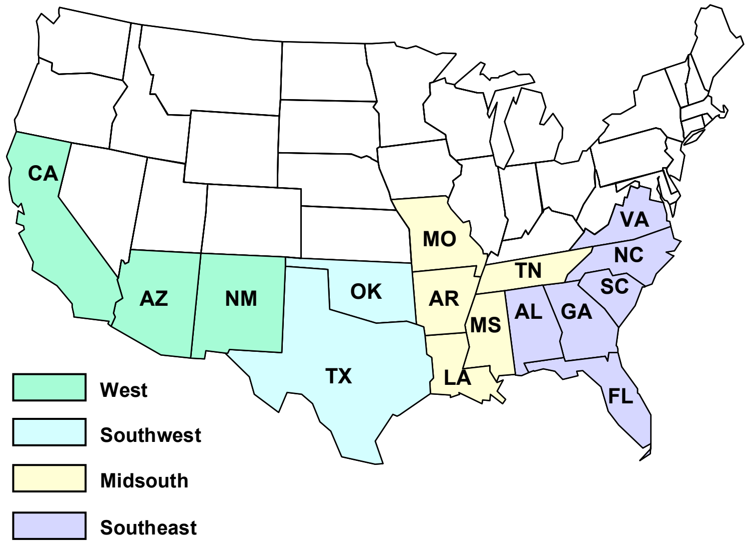

Figure 5. Cotton-growing states

Cotton fiber is produced on the plant in bolls. Each boll is composed of 3 to 5 locks of fiber adhering to seeds. Each lock can have 7 to 9 seeds, and a single seed can have 10,000 to 20,000 fibers. Thus, a 5-lock boll of fiber can have a half million fibers.

Fiber production depends on the plant variety, region, nutrients, weather, and other related factors such as damage by insects, bacteria, or fungi.

The stages of cotton fiber formation are shown in Figure 6. From the top left, these stages include the formation of a boll, flowering, growth of the fibers inside the closed boll, opening of the boll (ending the growth cycle), and drying out of the boll. Figure 7 shows a dried and a fully open and mature cotton boll.

Figure 6. Growth stages of cotton fiber formation

Figure 7. Dried and open cotton bolls

Cotton fiber from the field is composed of 87% to 90% cellulose and 5% to 8% water, the remainder being natural impurities. The cellulose content increases with fiber maturity. Large proportions of immature cotton fibers can result in various types of problems in textiles. The moisture content of cotton varies depending on storage conditions, and the amounts and types of impurities vary depending on growth region, fertilizer, and variety.

3.2 Ginning of Cotton

The purpose of the cotton gin is to mechanically separate the cotton fiber from the seed. Ginning is also used to remove non-cotton materials from the lint. If done too aggressively, ginning can increase the short-fiber content within a bale. After ginning, the fibers are compressed into cotton bales weighing from 480 to 500 pounds (210 to 220 kilograms). The bales are then shipped to textile mills, where they are spun into yarns for fabrication or shipped to non-woven textile facilities for web formation.

3.3 Physical Properties of Cotton Fiber

Cotton fiber growth — and therefore quality — depends on many variables:

- variety
- soil type and condition
- rainfall
- irrigation practices
- fertilizers
- temperature
- cultivation methods
- insect damage
- length of growing season
- exposure of open cotton boll to weather before harvest
- method of harvesting
- method of ginning

3.3.1 Microscopic Appearance

In cross-section, the cotton fiber is composed of four main parts:

- a **waxy layer** (the **cuticle**), which is water repellent and an excellent lubricant
- the **primary wall**, which contains natural impurities
- the **secondary wall**, which is pure cellulose
- the **lumen**, which is the open space in the center of the fiber through which the nutrients flow

In addition, cotton fibers have convolutions (twists) along their length, which give excellent fiber-to-fiber cohesion in spun textile yarns.

While actively growing, the cotton fiber is round. The perimeter of the fiber is distended by the pressure of the liquid nutrients and protoplasm inside the lumen. As cellulose is added to the fiber, the perimeter does not increase, but the lumen becomes smaller. At the end of the growing cycle, the fiber dies and collapses and the liquid disappears, leaving an almost empty lumen running lengthwise through the center of the fiber. Once the boll opens, the fiber dries out, and the dehydrated fiber takes on a kidney-bean cross-sectional shape. Figure 8 shows a cross-sectional view of the parts of the cotton fiber.

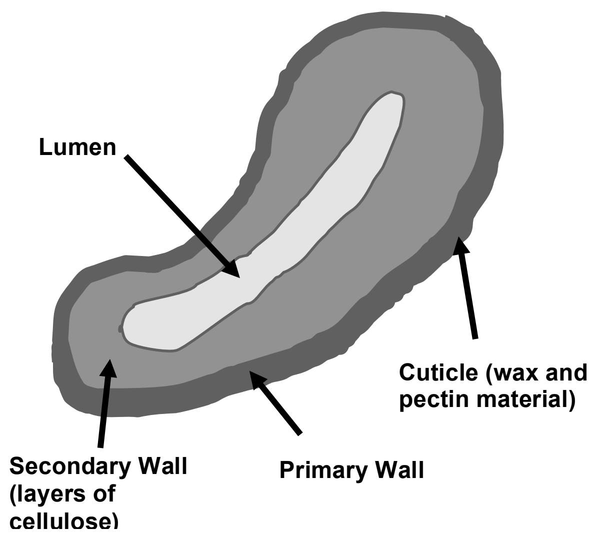

Figure 8. Cross-sectional view of a cotton fiber

The outer surface of the fiber, the primary wall, is a tough protective layer that forms during the early days of growth inside the boll. The surface of the cotton fiber is wrinkled like a prune, as a result of shrinkage as the fiber dries. Chemical analysis of the primary wall material shows that it contains wax, protein, and pectinacious substances, as well as some cellulose. When the non-cellulosic materials are chemically removed, the cellulose fibrils can be seen with the help of the electron microscope. They appear as a felt-like mat of tiny threads.

The inner layers, or secondary wall, of cellulose form the bulk of the cotton fiber. The secondary wall is almost pure cellulose and makes up 90% of the total fiber weight. This cellulose is laid down during the second stage of fiber growth, after the fiber has attained its full length, when consolidation of the cellulose wall takes place. The fibrils of the secondary wall are packed together in a near-parallel arrangement. The layers of fibrils lie in a spiral formation along the fiber axis (lengthwise), the direction of the spirals often reversing in the same layer. This reversing is the cause of the convolutions seen in the longitudinal view of a fiber. The result of this configuration is immense longitudinal strength.

Figure 9 shows the cut end of a fiber bundle, revealing a range of fiber development. The thicker the fiber, the more mature it is. The wrinkles on the surface of the fiber can be seen. In the upper center is a very mature fiber, and in the lower left corner is a much less mature fiber.

Figure 9. Cross-sectional view of a bundle of cotton fibers

A single cotton fiber has from 150 to 400 convolutions per inch. The direction of the twist may change along the fiber axis. The convolutions are very important to the cohesion between fibers in a yarn, which is necessary for strength. Figure 10 shows a microscopic view of the fiber convolutions.

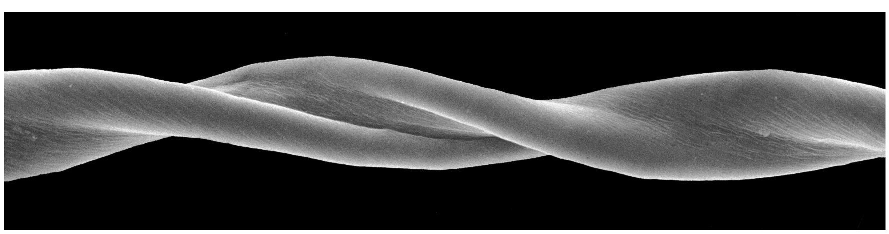

Figure 10. Longitudinal convolutions of a cotton fiber

3.3.2 Physical Properties

See the Appendix for a comparison of cotton's properties with those of other fibers.

Fiber length. Cotton fiber length depends first on the variety and then on the growing conditions. In general, cotton fibers range in length from 0.25 to 2.5 inches. Pima and

Egyptian cotton have the longest fibers. Most American cottons range from 0.75 to 1.4 inches.

Color. Although cotton fibers may naturally be grayish white, cream, gray, brown, or olive green, over 99% of cultivated cotton fiber is off-white or cream. The longer-staple fibers, such as Pima and Egyptian cotton, are more cream-colored.

Luster. Cotton is a low-luster fiber, because of its convolutions. Mercerization of yarn or fabric can improve the luster by permanently swelling the fiber. In general, more-mature cotton fibers are longer, stronger, finer, more lustrous, and generally more expensive. Fiber, yarn, and fabric luster can be altered by chemical and mechanical finishing processes.

Strength. Cotton fibers are moderately strong, with values ranging from 3 to 5 grams-force per denier. A unique feature of cotton fiber is that it becomes 10% to 20% stronger when wet. The strength is acceptable for most apparel and home-product end uses. Also, mercerized cotton is significantly stronger than natural cotton fiber.

Elasticity. Cotton fibers are slightly elastic, sufficient for apparel and home-product applications. Elasticity is increased by the convolutions of the cotton fiber. Elastic recovery from stress is 0.70 to 0.74 at 2% elongation.

Resiliency. As a result of their low elasticity, cotton fibers have low resiliency. As a result of this low resiliency, cotton products typically wrinkle when worn. Performance can be improved by chemical and mechanical finishing processes.

Moisture regain/absorption. Cotton's moisture regain under standard conditions is about 7% to 8.5% (10.3% for mercerized cotton). Its moisture absorbency at 95% to 100% relative humidity is 24% to 27%. The ability to absorb moisture makes cotton an outstanding choice for comfort wear in hot and humid conditions. Because of its high moisture absorbency and strength when wet, cotton is the standard for toweling.

Thermal properties. Cotton fiber scorches and turns brown at 245°C (475°F) and disintegrates above that temperature. Long exposure to dry heat above 150°C (300°F) gradually decomposes the fiber. The safe ironing temperature for cotton is 204°C (400°F). Cotton cannot be heatset, and it is biodegradable.

Specific gravity. A 100% cellulosic polymer has a specific gravity of 1.54. Greige cotton fiber has a specific gravity of 1.27, while the specific gravity of scoured and bleached cotton fiber is 1.54.

Effect of acids. Cotton fiber can be disintegrated by hot dilute acids or cold concentrated acids (such as sulfuric acid), but is unaffected by cold weak acids.

Effect of alkalis. Cotton is not adversely affected by alkalis. In fact, treatment with strong solutions of alkali, especially sodium hydroxide, can have positive effects. For example, treatment with 25% sodium hydroxide causes swelling and a change in the cellulosic structure, a process called **mercerization**. Under tension, the cotton fiber or fabric will attain a high degree of luster. Treatment of cotton with strong solutions of ammonium hydroxide also provides positive results. Under the right conditions, the process of liquid ammonia treatment (Sanforset) gives cotton improved abrasion resistance and wrinkle resistance.

Effect of organic solvents. Cotton is resistant to most common industrial and household solvents. This is a key to the success of cotton processing in dyehouses and in consumer care of cotton products.

Breaking tenacity. Cotton has moderate to high strength, sufficient for almost all textile products. An unusual characteristic of cotton is that it becomes stronger when wet. The strength of dry cotton ranges from 27 to 44 grams-force per tex (3.0 to 4.9 grams-force per denier), but the strength of wet cotton ranges from 28 to 57 grams-force per tex (3.3 to 6.7 grams-force per denier).

Breaking elongation. Breaking elongation of cotton fiber ranges from 3.0% to 9.5%, sufficient for all textile processes.

Sunlight and mildew resistance. Cotton has excellent resistance to sunlight. Fabrics subjected to excessive mildew should be laundered immediately to minimize residual effects.

Average stiffness. Cotton fiber is not a very stiff fiber, having low to medium resiliency. For this reason, cotton is not used for many carpet applications. Stiffness is in the range of 513 to 540 grams-force per tex (57 to 60 grams-force per denier).

Identification by burning. Upon ignition, cotton fiber leaves fine gray ash and no glassy bead.

3.4 Cotton Fiber Quality Measurement

Traditionally, cotton quality was judged by skilled, experienced people known as "cotton classers." Today, every bale of upland cotton grown in the United States is tested and classified by the U.S. Department of Agriculture (USDA) through the use of High Volume Instrument (HVI) systems. These computerized HVIs are also used by textile mills worldwide to better select and manage the cotton they buy. The HVI testing line is fully automatic. USDA testing centers located throughout the U.S. cotton-growing regions classify each bale as to length, length uniformity, strength, elongation, micronaire, leaf (trash content), color, and maturity. Figure 11 shows an HVI.

Figure 11. High Volume Instrument for testing cotton fiber

Another important fiber property is stickiness. Honeydew deposited by insects causes the fiber becomes sticky during processing, making yarn manufacturing extremely difficult.

Staple length and **length uniformity** are key to the merchandizing and use of cotton. In general, longer fiber means stronger yarn and fabric. Better length uniformity means less unevenness of yarn and fabric. The length of the cotton fiber depends first on the variety and then on growing conditions and ginning processes.

Micronaire is a combined indicator of fineness and maturity. It is a measurement of the air permeability of a constant mass of cotton fibers compressed to a fixed volume. Micronaire units are roughly equivalent to microgams per linear inch. Cotton fibers typically range in micronaire from 3.5 to 5.0. Micronaire affects yarn strength and dyeing. Lower micronaire makes a stronger yarn, with more fibers per cross-section. Lower micronaire also means lower apparent color yield, as a result of greater light scattering.

Fiber strength (breaking strength) is measured by the HVI in grams-force per tex.

Color grade is a measurement of **reflectance** (Rd) and **yellowness** (+b). Reflectance indicates the brightness or dullness of the fiber sample, and yellowness indicates the degree of color pigmentation. These machine measurements are converted to a color grade based on the Color Grade Chart for U.S. upland cotton. High color variation in a laydown will affect dyeing and shade control. Color grade is most affected by rainfall, freezes, insects and fungi, and staining through contact with soil, grass, or leaves. Excessive moisture and temperature levels during storage, both before and after ginning, also have an impact.

Leaf grade, also called "classer's leaf grade," is a visual estimate of the amount of leaf particles in the cotton. Leaf grades range from 1 to 7 plus "below grade," with a grade of 1 indicating the smallest amount of leaf particles. The cotton being graded is compared against standardized **grade boxes** for each growth year. The most important factors in leaf grade are harvesting methods, harvesting conditions, and the level of cleaning and drying during ginning. Figure 12 shows two grade boxes.

Figure 12. Cotton fiber grade boxes used to determine leaf grade

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APPENDIX: COMPARISON OF FIBER PROPERTIES

Fiber	Density (g/cm^3)	Regain (%)	Dry Tenacity (gf/den)	Wet Tenacity (gf/den)	Breaking Elongation (%)
Acrylic	1.18	2.5	2.2–2.4	1.8–2.0	20–50
Cotton	1.54	7.0	3.0–5.0	3.3–6.0	3.0–10.0
Flax (Linen)	1.50	8.75	5.5–6.5	6.0–7.8	2.5–3.0
Silk	1.25	11.0	2.4–5.1	2.0–4.3	10–25
Wool	1.30	13.6	1.0–1.7	0.7–1.5	20–40
Acetate	1.30	6.5	1.2–1.4	0.8–1.0	35–45
Nylon	1.14	4.5	2.3–5.0	1.8–4.0	19–40
Olefin	0.90	0.0	2.0–3.5	2.0–3.5	15–80
Polyester	1.38	0.4	2.5–9.0	2.5–9.0	10–60
Rayon					
regular	1.50	11.0	1.0–3.0	0.5–1.5	20–25
high tenacity	1.50	11.0	3.8–5.3	1.9–3.2	9–26
high wet mod.	1.50	11.0	4.0–5.0	2.2–3.0	15–23
Spandex	1.20	1.3	0.5–1.5	0.5–1.5	700

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