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Natural Cellulosic Fibers

Cellulosic fibers are derived from one of three parts of a plant (i.e. the flower or seed, stem, or leaf) and differ based on their origins. *Seed* fibers are fibers that come from the flower or seed of a plant; *bast* fibers come from the stem of the plant. While bast fibers from different types of plants (e.g., flax or hemp) more often reveal their commonalities under a microscope, there are certain differentiable morphological characteristics that can be identified. For example, the longitudinal characteristics of linen appear as having nodes or kinks, which are similar to that of hemp's longitudinal characteristics; however, their cross-sectional view differ as hemp has a wider lumen than linen.

Fiber morphology is the study of the structure and form of fibers and requires the utilization of microscopes to see the true characteristics of the fiber. When we view the fibers under a microscope, we see either *longitudinal* or *cross-sectional* fiber characteristics (which will both be discussed in this book).

1.1 Seed Fibers

1.1.1 Cotton

Cotton comes from the flower of cotton plant, which is of the genus *Gossypium* in the mallow family Malvaceae. There are few types of the plant. Cotton is an ancient fiber as it has been used for clothing articles for thousands of years. Archeological evidence suggests that cotton was used in Pakistan more than 5000 years ago and in Mexico 3000 years ago, which makes sense because the cotton plant grows in warm climates.

Today, cotton is the most commonly used natural fabric. Its desirable properties such as comfort, absorbency, and good conductor of electricity have made it difficult to replace it with other fibers.

As already mentioned, the longitudinal characteristics of cotton fibers are ribbon-like twists or also often called convolutions (Figure 1.1). These twists can be closer together or further apart depending first on the age of the plant

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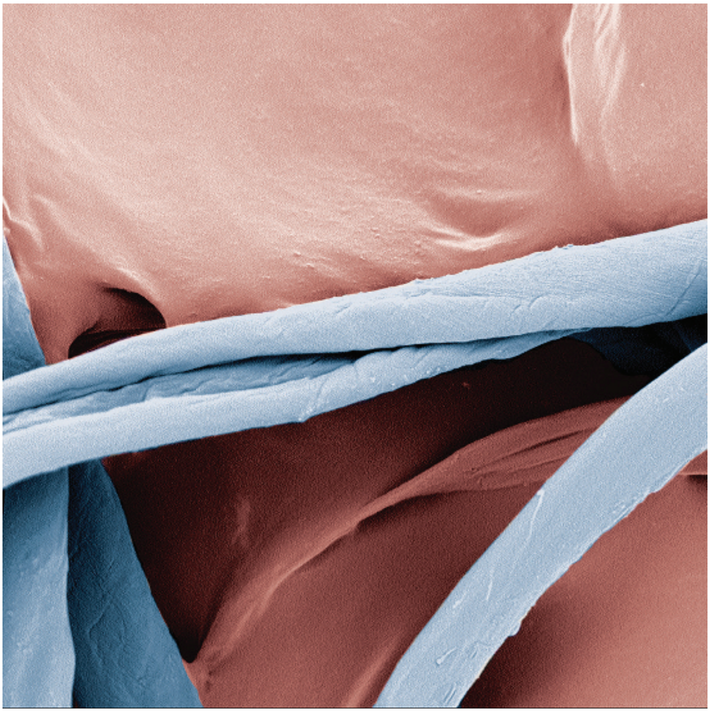


Figure 1.1 Longitudinal view of pima cotton fibers featuring ribbon-like twists (2000×).

and second on chemical fiber applications. The cotton fibers that come from a fully ripped bud will have twists closer together, and therefore a little bit more easy to identify under the microscope, than the cotton fibers that come from an half-ripe bud, also called immature fibers [1], which will have twists that are further apart and therefore more difficult to identify under the microscope. When the cotton bud is unripe (immature fibers), the fibers will have very minimal twists or no twists at all. The twist starts forming after the cotton boll opens. Not all cottons have the same amount of twists/convolutions. High-quality long staple cotton has about 300 convolutions/in., and low-quality short staple cotton has no more than 200 convolutions/in. [2].

The advantage of the fiber twist is that it allows the fibers to cling together, and spinning yarns even out of short-length fibers would not be difficult [2]. Also, twists enable cotton fabrics to be more elastic and not stiff like other cellulosic fibers such as linen fabrics. The twists also give cotton its uneven surface which in turn enables only a random skin contact, making the fabric comfortable to wear.

Another reason why these ribbon-like twists could not be easily identified under the microscope is the chemical application called mercerization, which is "a chemical treatment applied to fibers to permanently impart a greater affinity for dyes and various chemical finishes" [3]. The fibers are immersed in a sodium hydroxide solution, which will give cotton fibers greater absorptive properties, higher degree of luster, and higher strength. Mercerization of cotton fibers will change the shape of the fibers because this chemical treatment will cause the fiber to swell, and thus, twists will be flattened out and not easily seen under the microscope (see Figure 1.2).

The cross-section of cotton fibers could also vary in shape based on the maturity of the fiber. In a cotton boll, there are always some immature fibers mixed with mature ones. The mature fibers have a round cross-sectional shape, thick cell wall, and a small lumen (also referred to as central canal). On the other hand, immature fibers do not have round cross-section but have a U shaped cross-section with a thin cell wall (see Figure 1.3). Immature fibers are not desirable because they are more difficult to spin into yarns and to dye [2]. Immature cotton fibers appear collapsed under the microscope. We can explain these differences in more detail by identifying the different parts of the cross-section. There is the outer wall of the fiber, which is also called the primary wall, the inner wall, which is also called the secondary wall, and the center of the fiber cross-section, which is called the lumen (see Figure 1.2). Lumens are the hollow regions in the center of the cross-section. "The reasons for invisible lumens in some cross-sections are that the fibers are either so mature that the inner spaces are fully filled or immature that the openings are totally collapsed" [1, p. 412].

We learn a great deal from knowing about the lengths and widths of fibers as they affect fabric performance and properties. Cotton fibers are generally

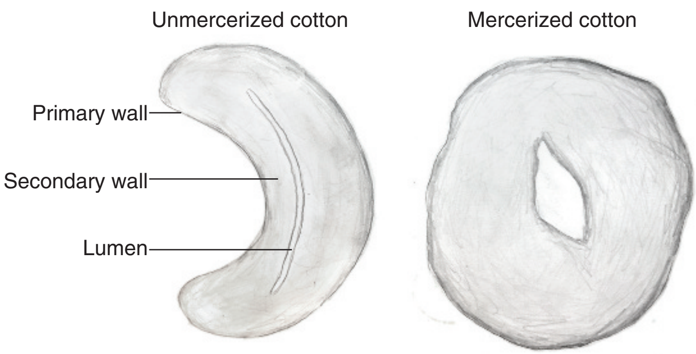


Figure 1.2 Physical structure of cotton fibers.

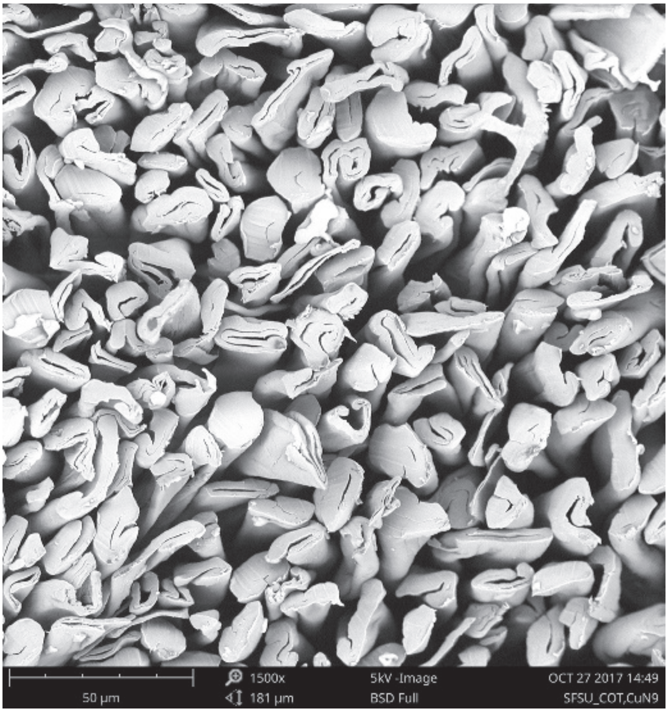


Figure 1.3 Cross-section of cotton fibers with a variety of wall thickness showing mature fibers with thick cell wall and a small lumen and immature fibers U shaped cross-section with a thin cell wall (1500×).

around 1 in. long; longer cotton fibers generally range from 1½ to 2 in. Cotton fiber length has an effect on fabric properties; the longer the fiber, the better the quality of the fabric. Longer cotton fibers yield a smooth, soft, and lustrous fabric, which is the reason why such fabrics are more expensive and desirable (Figures 1.4 and 1.5). Fabrics made out of long staple cotton fibers are called *Pima, Supima, Egyptian,* or *Sea Island* cottons; cottons with shorter fiber lengths are called *upland* cottons (see Figures 1.6–1.8 for a variety of cotton fibers).

End use: Apparel – undergarments, pajamas, dresses, and children's wear. Interior – curtains, tablecloths, and beddings.

1.1.2 Organic Cotton

Organic cotton is a more sustainable alternative to conventionally grown cotton because it does not use chemicals and pesticides for its growth. Although conventionally grown cotton is a natural fiber, it is not considered to be a

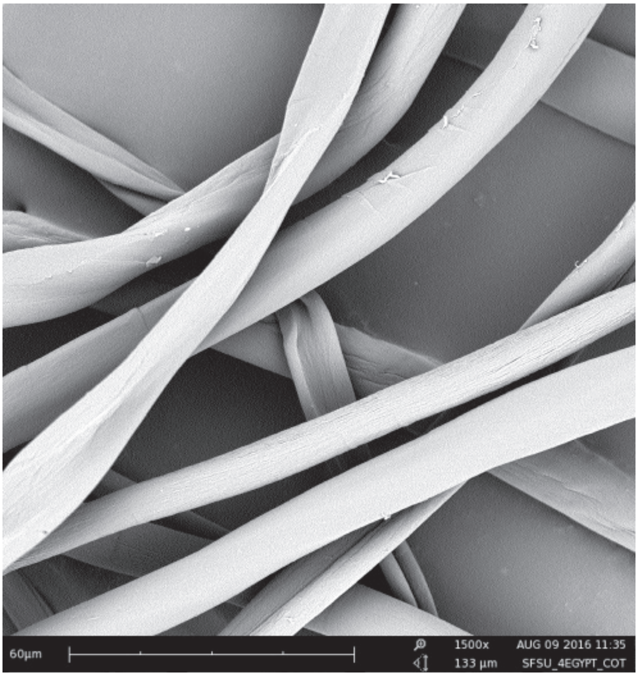


Figure 1.4
Longitudinal view of Egyptian cotton fibers – extra-long fibers of high quality (1500×).

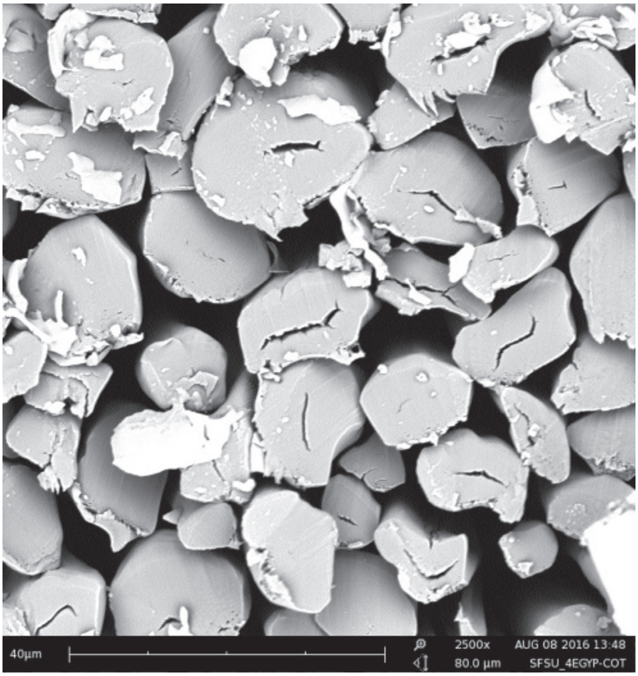


Figure 1.5
Cross-sectional view of Egyptian cotton fibers (2500×).

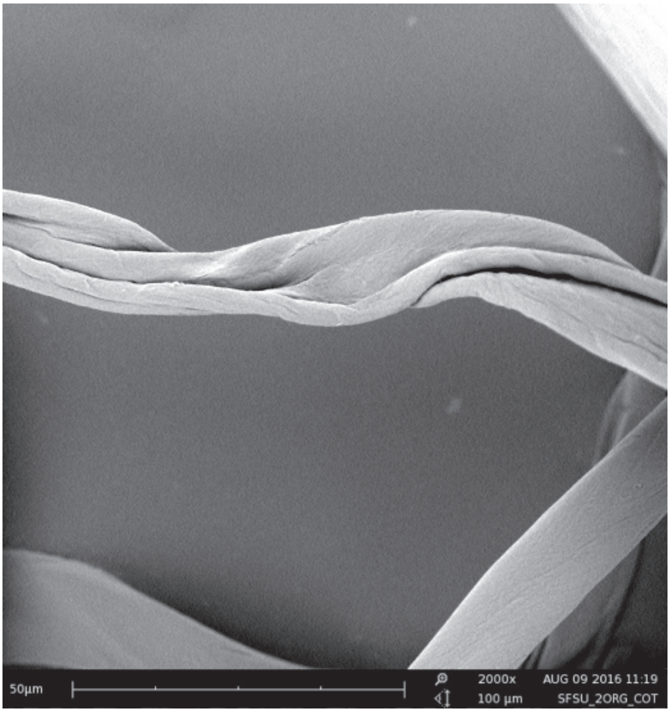


Figure 1.6 Longitudinal view of organic cotton fibers showing ribbon-like twists (2000×).

sustainable fiber because it uses excessive amount of water, chemical fertilizers, and synthetic pesticides during growth. Under a microscope, organic cotton has similar fiber characteristics to conventionally grown cotton (see Figures 1.6, 1.7, and 1.9). The major end uses of organic cotton include wearing apparel, baby clothing, and bedding.

1.1.3 Kapok Fibers

Kapok (Ceiba pentandra) is a seed fiber (e.g. like cotton) derived from the fruit of a tree. Due to their hollowness, the fibers are considered to be the lightest natural fibers in the world [4]. Kapok fibers are shorter than cotton fibers, which negatively affect their strength [5], and their morphology is quite different as well. When viewed under a microscope, the longitudinal characteristics of the fiber resemble microtubes and are not as convoluted as cotton [6]. Their smooth cylindrical surface gives the fiber a natural luster that resembles silk fiber [4]. Also, kapok fiber has a thin wall, which is covered with a thick layer of wax; this makes this fiber nonabsorbent and gives it a hydrophobic property. The waxy surface will immediately repel water, not allowing it to go beyond the

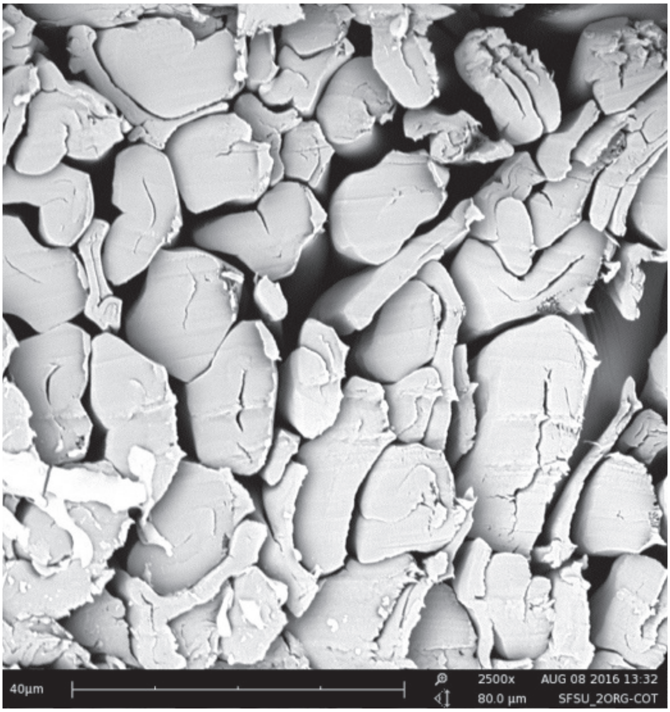


Figure 1.7 Cross-sectional view of organic cotton fibers (2500×).

waxy surface. This is very different from cotton, which is a highly absorbent fiber.

Kapok's nonabsorbent fibers are also difficult to dye, resistant to swelling, and have atypical large hollow lumens, which do not collapse like cotton [7]. In fact, the cross-section of kapok fiber shows a wide open lumen [8], which is oval or sometimes round in shape [7] and is filled with air [4] and large air bubbles [7]. Kapok fibers likely possess the greatest hollowness of all natural fibers [6]. The hollow degree can reach up to 80–90% of hollowness, which allows the kapok fibers to retain warmth and be used as thermal insulators, sound insulators, and water lifesaving materials [9].

Kapok fibers are short (e.g. compared to cotton); they are 10–35 mm long, with diameters of 20–43 mm [7]. Their short length prevents the fibers from being spun into yarns. In fact, to be used for textiles [10], they must be blended with cotton fibers. However, in a kapok/cotton blend, the kapok content should not exceed 50% to yield the best result [11].

Interestingly, although kapok fibers do not absorb water, they do absorb oil [6]. Thus, the wetting liquid for kapok is oil, and the nonwetting liquid is water [12]. This oil-absorbent property is of interest to ecologists and

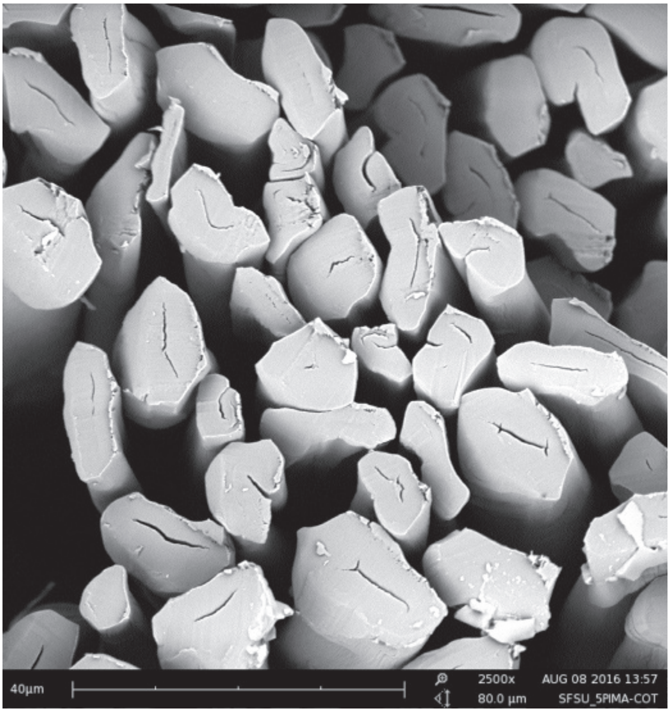


Figure 1.8 Cross-sectional view of pima cotton fibers – long staple fibers (2500×).

environmentalists because the material can be of use during oil-spill cleanups. Researchers attribute this oil-absorbent property to the fiber's micro-nano-binary structure [13]. On the surface of the fiber, there are two coats of protective layering so that water droplets do not penetrate the fiber wall; these layers are on micro and nano levels.

End use: Kapok fiber is light, very buoyant, resilient, and resistant to water. It is used as filler in pillows, mattresses, insulation, and soft toys.

1.1.4 Poplar Fibers

Poplar fibers (*Populus*) are another kind of seed fiber; they were brought to the public's attention in the last decade by German scientists who announced it as the fiber of the year in 2006 due to the sustainable way it is grown. Researchers are still trying to figure out the best way to utilize this fiber in textiles; one of the problems with poplar fibers is that they are too short to be spun into yarns. The structure of poplar fibers is similar to kapok; however, they are shorter. A longitudinal view of the fibers reveals microtubes with smooth cylindrical shapes. The cross-section of the fiber is round with a thin wall and a large hollow lumen.

Figure 1.9 Longitudinal view of organic cotton fibers depicting similar fiber characteristics (ribbon-like twists) to conventionally grown cotton (2000×).

Even though poplar (vs. kapok) fibers are small, their hollow spaces are relatively large (i.e. 89% vs. kapok's 77%) [12]. Thus, the density of poplar (vs. kapok) fibers is lower. Poplar fibers also possess hydrophobic ability (i.e. they repel water but absorb oil). Thus, it would be difficult to apply dye stuff on poplar seed fibers; the fibers are therefore mainly used as insulation or stuffing materials. In fact, technology has not yet developed a way to utilize poplar fibers in the clothing industry. Similar to kapok fibers, poplar fibers may be blended with cotton fibers to make them suitable for spinning. Because of poplar fiber's hydrophobic property, the fiber becomes a good oil-absorbent material [14]. The advantage of poplar seed fibers is found in their short length when it comes to oil absorbency. The shorter the fiber, the better the oil absorption capacity. Poplar fibers are around 0.95–1.59 in. in length and 8–14 μm in diameter.

1.1.5 Willow Fibers

Willow (*Salix*) fibers are seed fibers that come from the same tree family as poplar fibers. One of the advantages of willow (vs. poplar) fibers is the ease of harvest; also, these fibers are considered fibers of the future because they are ecofriendly and sustainable. The environmental benefits are found in their cultivation and growth as they do not require significant irrigation (e.g. as cotton does); also, the willow tree can help remove contaminants from the air, soil, and water surrounding it. Willow fibers have similar characteristics to kapok and poplar fibers. A longitudinal view reveals a microtube with a smooth, cylindrical shape; specifically, the fibers appear smooth and silk-like with some ribbon-like twists. The cross-section of the fiber appears round with a thin wall and a large hollow lumen (see Figures 1.10 and 1.11). Even though willow fibers are similar in structure to those of kapok and poplar, they are shorter and thus would be difficult to spin into yarns. Willow fibers are around 0.4–0.6 cm in length and 4–15 μm in diameter [15].

Potential future uses: These new ecofriendly/sustainable fibers can be utilized in many ways in textiles (e.g. in manufacturing fiber composites). They can also be used as insulators in jackets, pillows, or stuff toys and can be blended with other fibers.

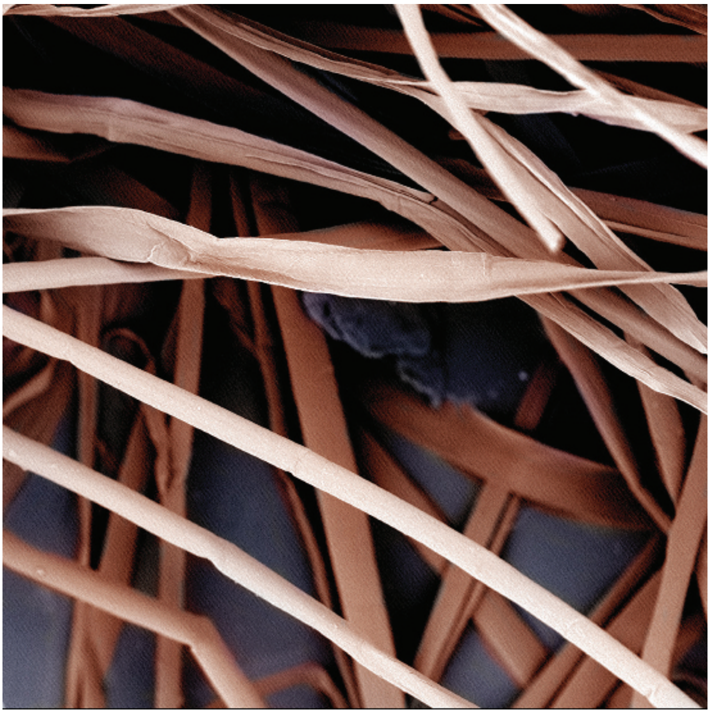


Figure 1.10 Longitudinal view of willow seed fibers depicting microtube with smooth, cylindrical, and ribbon-like shape (1000×).

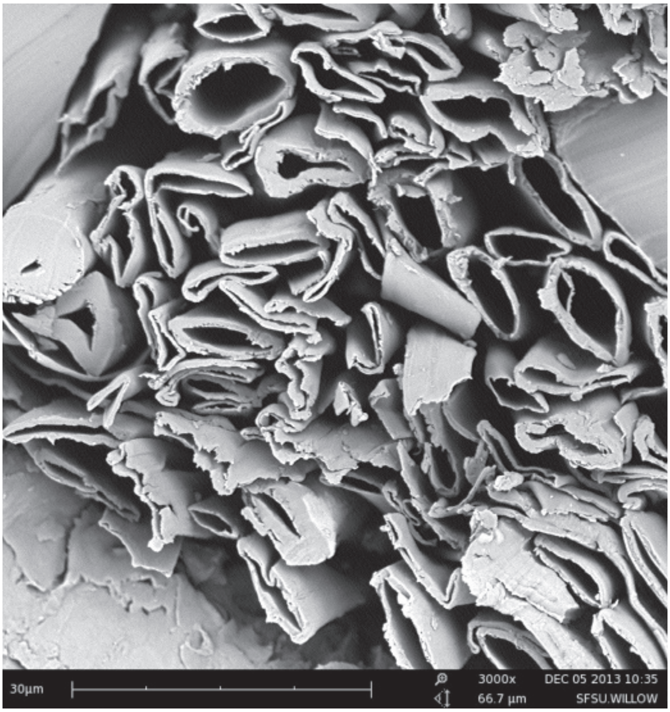


Figure 1.11 Cross-sectional view of willow fibers showing round, thin wall with large hollow lumen (3000×).

1.1.6 Coir Fibers

Coir fibers come from the outer shell of coconuts, are coarser than the other seed fibers previously discussed, and are grouped into one of two categories. The first group is extracted from mature coconuts, and it is brown in color and coarser. The second type is extracted from immature coconuts; the fiber is finer and white in color. However, overall, coil fibers are inherently stiff and ductile. The fibers have a rough, textured surface under a microscope. Their most distinctive characteristic is a highly porous surface. However, the cross-section of coir fibers is somewhat similar to kapok, poplar, and willow fibers because of the significant hollowness of the fibers. Coir fiber has a large, hollow, tube shape with very thin walls. The size of coir fibers also makes them quite unique; they are much larger than other seed fibers. Their length reaches up to 35 cm, and they extend 11–25 µm in diameter.

End uses: Interiors – upholstery, rugs, doormats, mattresses, sacks, and insulation. It is also used for geotextiles.

1.2 Bast Fibers

Bast fibers such as flax, nettle, ramie, hemp, and jute have very similar morphological characteristics and thus are difficult to distinguish under the microscope. Distinguishing among these fibers is not done easily, but some researchers propose certain methods that help to point out some differences.

Bast fibers, whether soft or hard, are easily distinguished from other cellulosic seed fibers or protein fibers. Bast fibers have a distinguishing characteristic in longitudinal view, many of them have cross-marks (single oblique lines) on the fiber surface. These cross-marks are "cell dislocations which are usually accentuated by the mechanical treatment during processing to extract the fiber from the plant" [16, p. 123]. The cross-sectional view usually (for most but not all bast fibers) entails a polygonal shape and lumen (which is an opening cavity in the center of the fiber).

The fibers' cross-section shape would be the only way to distinguish some of the bast fibers. For example, there are similarities between flax, hemp, and jute fibers' cross-sectional shape as they have a rounded polygonal outer shape with an oval or round narrow lumen. Ramie and nettle fibers' cross-sectional shape differs slightly from the aforementioned fibers. The latter have a more elongated not as polygonal and round cross-sectional outer shape and have a larger lumen [17]. Bast fibers such as nettle, hemp, and jute are important to identify mainly when dealing with archeological finds, as today they are not used in large quantities in clothing.

1.2.1 Linen

Linen (Linum usitatissimum) is a widely used fiber, comes from the stem of the flax plant, is also referred to as flax, and has a harsher texture than that of seed fibers (e.g. cotton). Bast fibers have many similar properties to other cellulosic fibers (e.g. absorbency, good electrical conductivity, and comfort); however, bast fibers have a harsher hand than seed fibers. This property is reflected in the fiber shape, which we can see under a microscope. Linen is an ancient fiber, and there is plenty of archeological evidence that it was used for clothing for thousands of years in Egypt and in Europe.

Linen fibers have some variations in shape based on their source and quality; however, they also share some common characteristics. Under a microscope, longitudinally, linen fibers resemble bamboo sticks. Their bamboo-like joints (also called nodes) are key characteristics of linen fibers, distinguish them from seed fibers (e.g. cotton), and are cylindrical in shape (see Figures 1.12–1.14). These nodes add to the flexibility of the fibers (which bend at the nodes) and, of course, add to the texture of the fabric. In some cases, the nodes intersect like the letter X [18].

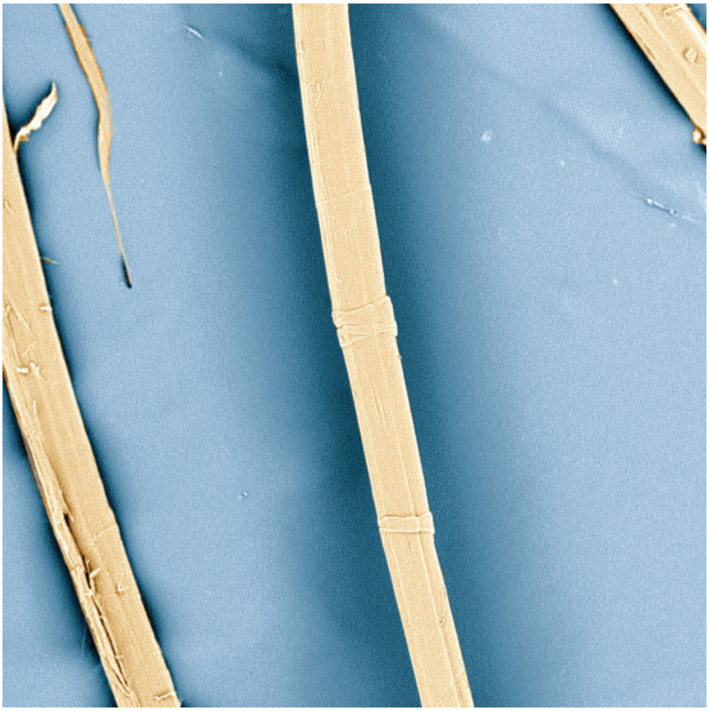


Figure 1.12 Longitudinal view of linen fibers showing cross-marking or nodes – resembling bamboo-like joints (1000×).

The cross-sectional shape of linen fibers is very different than that of seed fibers (e.g. cotton) as it is made up of irregular polygonal shapes. The fiber may have several polygonal sides with a small lumen, which is the center void portion of the fiber. "The cross-sectional contour of flax is sharp-edged, polygonal, slightly elongated. The lumen is visible as a small round to oval opening in the center" [19, p. 27]. The cell wall of linen fibers is very thick, and thus, the lumen looks like a narrow line; this significantly differs from seed fibers' hollow, tube-like, and cross-sectional shapes (see Figure 1.15). It is common to see fiber bundles when viewing cross-sectional shape of bast fibers under a microscope (see Figure 1.16). The size of linen fibers is much greater than that of seed fibers (e.g. cotton). The individual fibers are as long as 10–12 in. in length [20]; the approximate diameter is 15–17 μm.

End use: Apparel – suits, dresses, and blouses. Home interiors – draperies, upholstery, tablecloths, and dish towels.

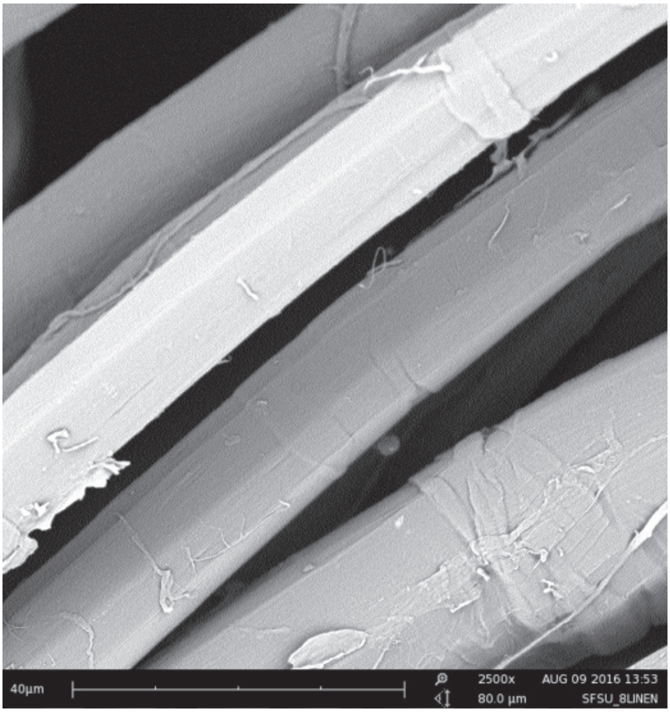


Figure 1.13 Further magnified view of linen's bamboo-like nodes (2500×).

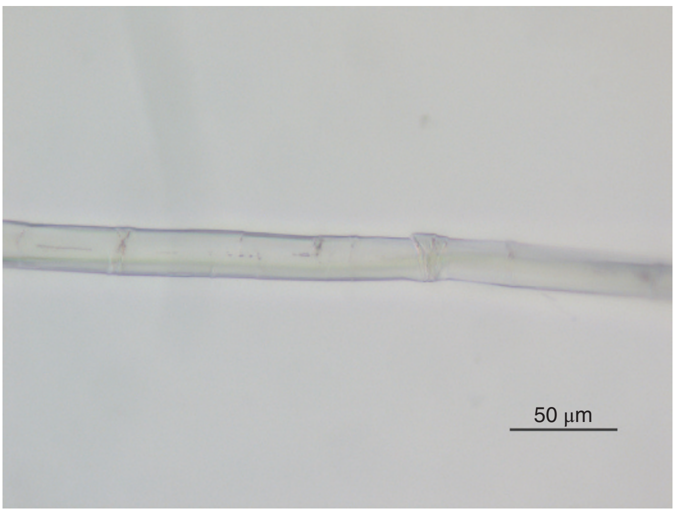


Figure 1.14 Linen fiber showing bamboo-like nodes through a compound microscope.

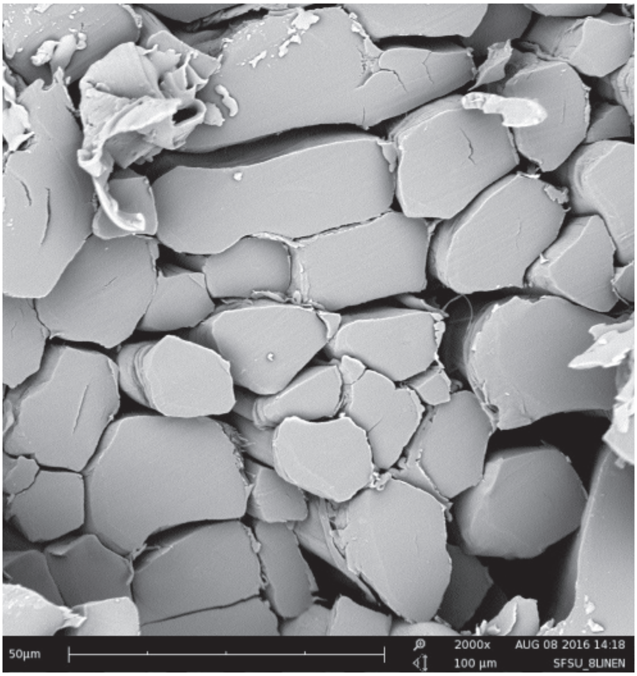
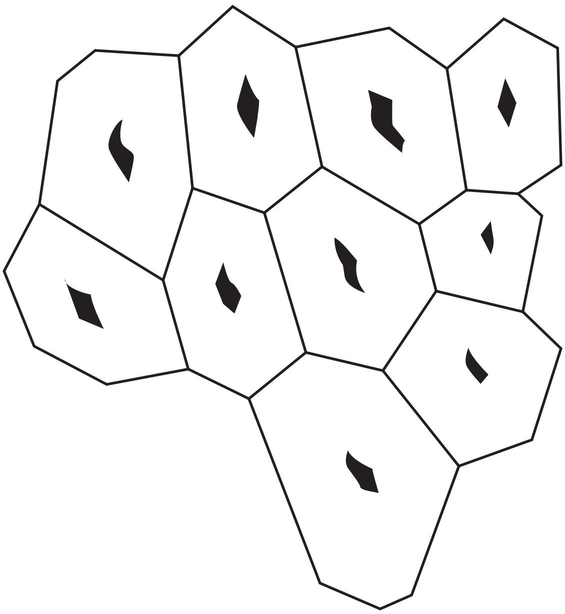


Figure 1.15 Cross-sectional view of linen individual fibers (ultimates) and fiber bundles. Individual linen fibers showing polygonal fiber shape (2000×).

Figure 1.16 Depiction of fiber bundles composed of individual fibers of polygonal shape. Bast fibers come in fiber bundles, which can be separated into fiber ultimates.



1.2.2 Ramie

Ramie (Boehmeria nivea), a bast fiber, which is a part of the Urticaceae (Nettle) family, is also known as China grass. Ramie plant is native to Southeast Asia (Philippines), China, Japan, and Brazil because warm and humid is the best climate for its growth. Ramie fibers have a great strength compatible to synthetic fibers [21]. Ramie has some properties of those of linen such as low elasticity, absorbency, stiffness, low resiliency, and high natural luster. Similar to flax, it breaks with frequent folding. End uses: Ramie is often blended with other fibers and used in blouses, shirts, and suits. Ramie is also utilized in home furnishings such as table cloths, pillows, and window treatments. Because of its strength, ramie is used for ropes, industrial sewing threads, and fishing nets. Polarized light microscopy (PLM) is suitable for anisotropic fibers such as these bast fibers. Besides the oblique cross-section markings, long and striated longitudinal lines (see Figure 1.17) are visible in bast fibers such as ramie. The distinguishing longitudinal characteristics of ramie fibers are pronounced diagonal cracks [19] (see Figure 1.18). Cross-markings or bamboo-like nodes are also seen in ramie,

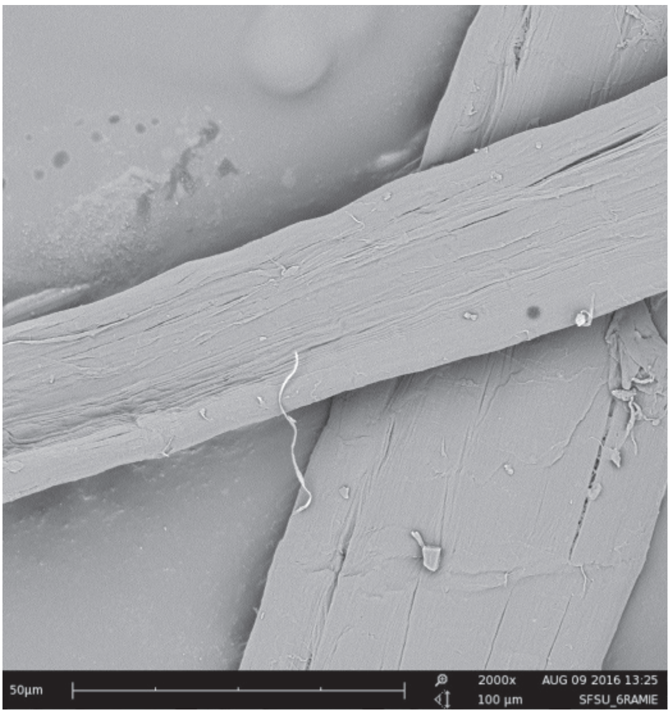


Figure 1.17 Further magnified ramie fibers showing fibrillary orientation typical of bast fibers (2000×).

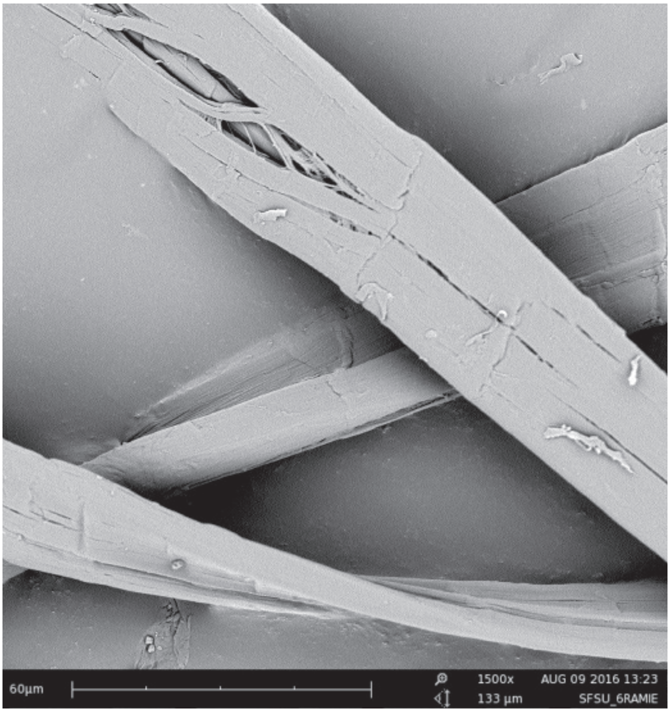


Figure 1.18 Longitudinal view of ramie fibers showing pronounced diagonal cracks (1500×).

but mostly under polarized microscope [19] (see Figure 1.19). Cross-sectional shape of ramie is similar to cotton, but it has a larger diameter [19]. The shape also varied from hexagonal to oval [19] (see Figure 1.20).

1.2.3 Hemp

Hemp plants (Cannabis sativa) grow in the northern hemisphere and include many different varieties of this plant species. Hemp fibers are coarser than flax fibers, and therefore, they are great to use for ropes [22]. Hemp fibers viewed under a transmitted light will show the longitudinal view nodes or kinks (or also called fiber dislocations). Also, when hemp fibers are viewed with scanning electron microscopy (SEM), fibers will show nodes (or dislocations) very similar to linen. See Figure 1.21. However, when magnification is increased above 1000×, the nodes are less visible, and bark-like lines (striations) could be identified (similar to jute) (see Figure 1.22). Therefore, higher magnification does not necessarily give better results. The cross-sectional view of hemp fibers are believed to be similar to those of flax and jute as they have a polygonal shape and a lumen in the middle. Some cross-sectional distinguishing

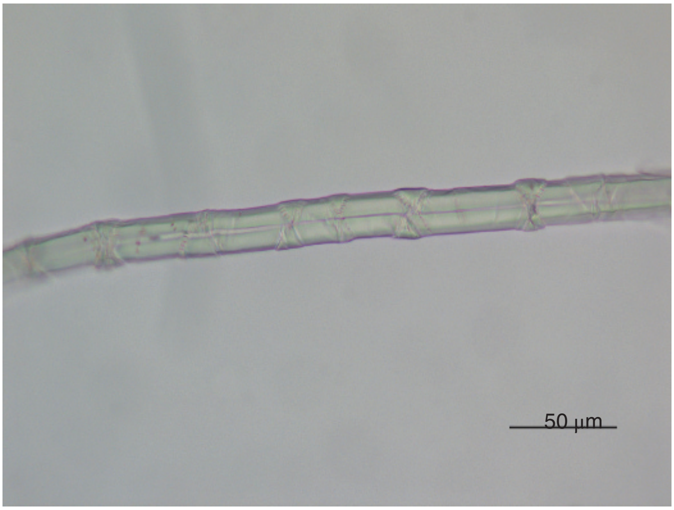


Figure 1.19 Longitudinal view of ramie fibers depicting cross-markings typical to bast fibers and viewed under compound microscope.

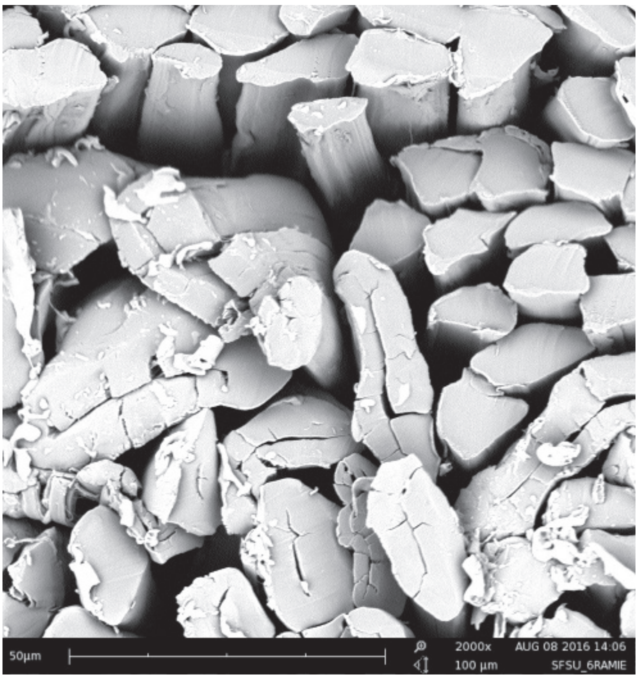


Figure 1.20 Cross-section of ramie fibers depicting a variety of features ranging from features found in cotton's cross-section, hexagonal, and oval (2000×).

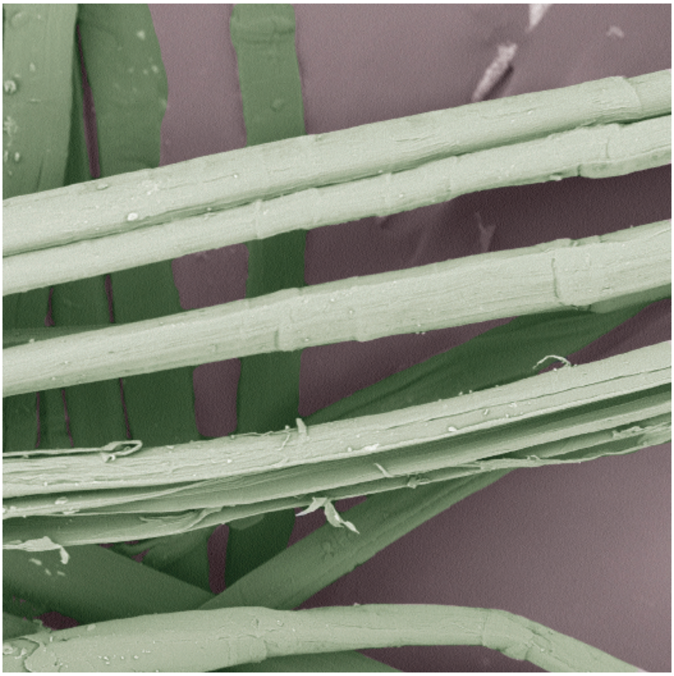


Figure 1.21 Longitudinal view of hemp fibers showing bamboo-like nodes typical for bast fibers (1000×).

Figure 1.22 With increased magnification (1500×), bamboo-like nodes are becoming less visible and bark-like lines (striations) are more prominent in hemp fibers.

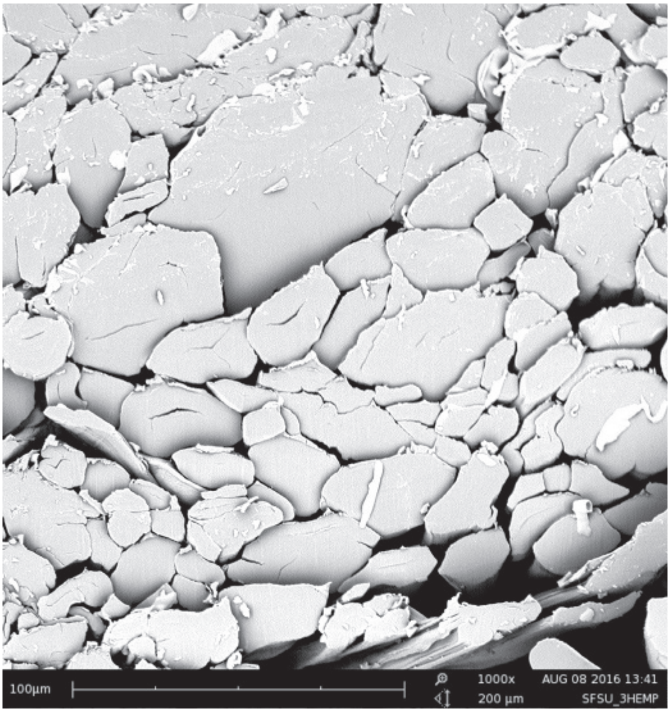


Figure 1.23 Cross-sectional view of hemp fibers depicting polygonal shape and a lumen in the middle (1000×).

characteristics from flax are that its corners are rounder, and the lumen appears as an elongated cavity in the middle [19] (see Figure 1.23). However, hemp has a wider lumen than flax [19], and its diameter is much larger in comparison to flax and jute (see Table 1.1). When viewing a single fiber via PLM, a thicker line

Table 1.1 Fiber diameter of bast fibers.

Fiber	Diameter (µm)	References
Flax	12–20	[23, 24]
Bamboo	6–12	[23]
	5–20	[25]
Hemp	32–34	[26]
	18–23	[19]
Nettle	19–47	[27]
	19–25	[28]
Jute	15–20	[19]
Ramie	30–70	[19]

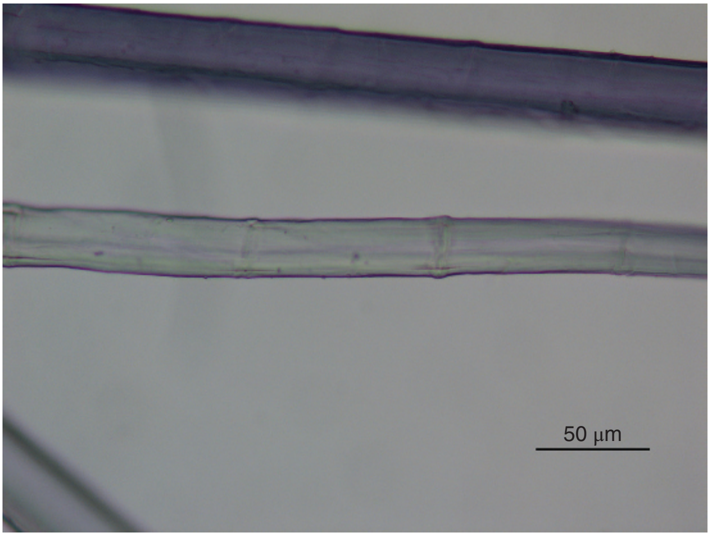


Figure 1.24 Longitudinal shape of hemp fibers using polarized microscope, which allows us to see a thicker line (striation) running down the middle of the fiber – lumen.

(striation) running down the middle of the fiber could be seen – this line would be the lumen (a cavity of the bast fibers) (see Figure 1.24).

1.2.4 Bamboo

Bamboo fibers have been used since ancient times especially in Asia. It has been used for many different purposes in Asian history such as papermaking and construction. The shape of bamboo fiber is smaller in comparison with a flax fiber [23]. The spindle-like short fibers are only around 1.9 mm in length and 15.3 μm in diameter, which have a tapered shape at both lengths. The fibers are densely packed within the fiber bundles, and their diameter is around 5–20 μm (mean of 13.16) [25]. Sizing of fibers could also be a distinguishing feature among bast fibers as bamboo fibers are much smaller in size from those of flax, hemp, and nettle fibers. Bamboo fibers are only 2 mm in length, and therefore, there are two ways in which bamboo fibers can be prepared for the textile industry. First, because of its short length, bamboo in its fiber bundle form can be processed chemically and physically treated [23]. Second, bamboo (is retted into bamboo pulp) fiber pulp is used to make bamboo regenerated fibers. The fibers from the latter method would have different morphological characteristics from the first method, as the latter method is similar to viscose rayon.

The longitudinal characteristics of bamboo fibers are similar to those of other bast fibers; however, two main fiber surface differences are present. First of these distinguishing characteristics is that when viewing a single bamboo fiber under the microscope, it is rough (appears as having tree-bark stripes) in its surface (rougher than flax or ramie). The second distinguishing characteristic is that bamboo fibers lack the nodes or cross marks, which are seen in flax or ramie fibers [23].

Bamboo fibers have more differences in their cross-sectional view as they have a round shape with a small round lumen, compared to polygonal shape (small lumen) of flax and ellipse shape (with lumen and cracks) of ramie [23]. Bamboo's cross-sectional shape and size could distinguish it from other bast fibers; although the shape of single bamboo fiber is far smaller than that of flax [23]. As a result, single bamboo fiber can be identified according to the characteristics of cross-section and size.

1.2.5 Jute

Jute fiber is yet another bast fiber that comes from the *Corchorus* genus plant family, which grows in India, Bangladesh, or China. Jute fibers are not as long as other bast fibers and therefore are difficult to spin. In addition to its inadequate length, jute fibers are also weaker than other bast fibers. Jute fibers are weak when wet and when exposed to sunlight and therefore are not used for as much for ropes and fishnets as other bast fibers. End use includes twine and cordage, but it is also made into a burlap fabric that is usually used for sacking, carpet backing, or in gardening and geotextiles. Jute fibers are coarse and therefore not commonly used in clothing products. Under a microscope, jute fibers share similar characteristics with other bast fibers as they have polygonal to oval cross-sectional fiber shape [19]. However, nodes and cross-marking are found only infrequently [19] (see Figures 1.25–1.29).

1.2.6 Fiber Size

One of the identifying characteristics can be the width of the fiber or the diameter of the fiber. Bast fibers vary in fiber diameters. Fiber diameter could be determined by the use of an ocular micrometer that could be attached to a microscope (see Table 1.1).

1.2.7 Nettle

Nettle is a part of the Urticaceae family and belongs to the genus *Urtica*. Stinging nettle and ramie are a part of the same family. The stinging nettle is the most common species grown in Europe. Nettle, flax, and hemp fibers have been extensively used in Europe in the past before the cotton industry took over. It was also a very important fiber in prehistory for Native Americans. Nettle is considered a biodegradable fiber as it comes from a renewable source

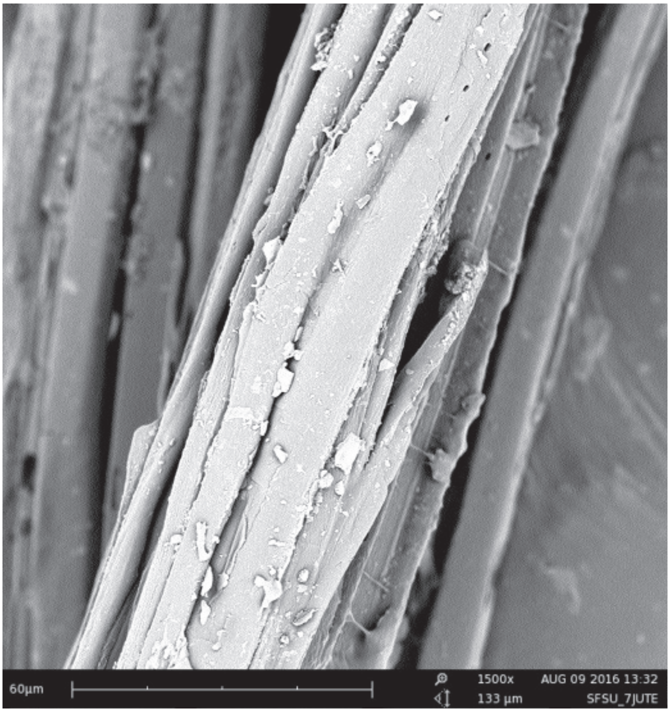


Figure 1.25 Longitudinal view of jute fiber bundles (1500×). Nodes are rarely seen in jute fibers.

and requires little water and energy for production. Nettle plant grows like weed, and it does not need extra work for growth. The longitudinal view of nettle fibers is nodes or kinks (cross-marks), again characteristics as seen in hemp and flax. The cross-section of nettle has a polygonal shape but more of an elongated band formed outer shape and a large lumen; this shape is similar to ramie.

Because some bast fibers have similar longitudinal and cross-sectional characteristics, they are difficult to identify under a microscope. New identifying methods have been utilized in identifying bast fibers, also with the use of microscopes. Two methods that will be discussed next are identifying the fibrillary orientation of bast fibers and the presence of crystals in bast fibers [17]. Both of these methods have distinguishing features and for best results should be used together. The first method, identifying fiber fibrillary orientation, is conducted with the use of PLM. An examiner focuses on the direction of the fibrillary cell of the bast fibers. These fibrils are basically bundles of microfibrils, which are positioned in a helical pattern along the length of the fiber [17]. The orientation of the helical pattern can go either to the left or to

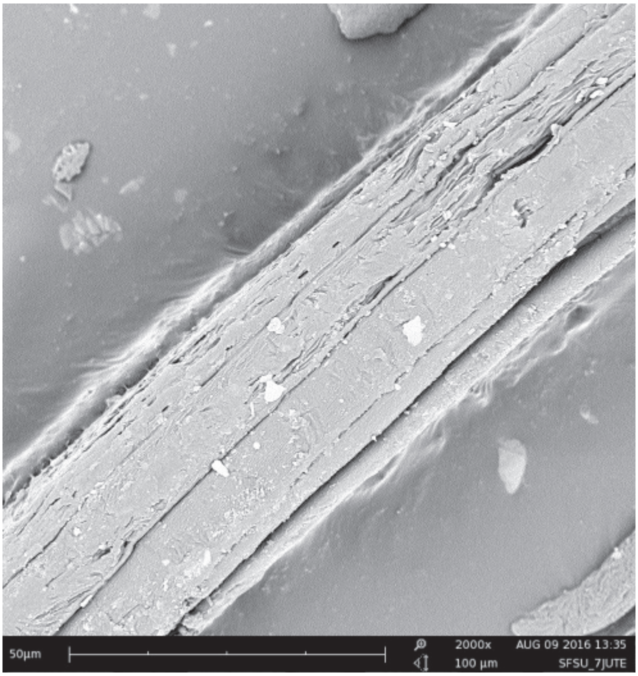


Figure 1.26 Further magnified (2000×) view of jute fibers depicting bark-like surface texture.

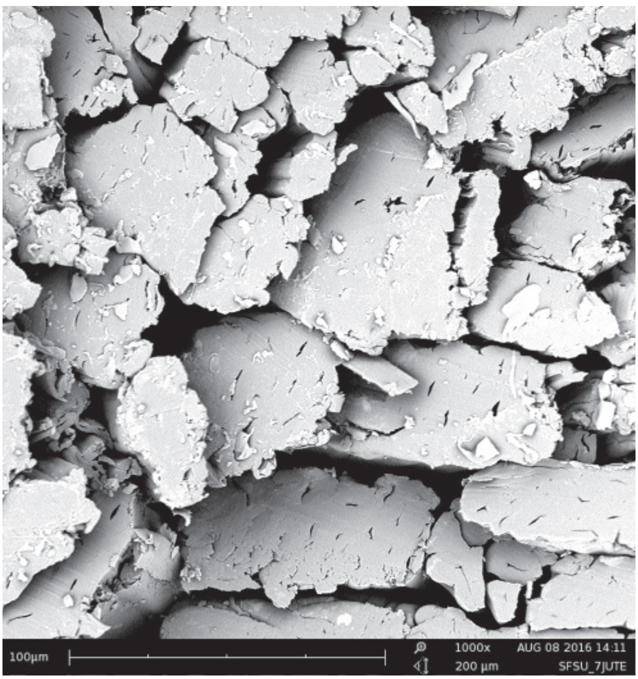


Figure 1.27 Cross-section of jute fibers (1000×). Fibers are mostly found in bundles.

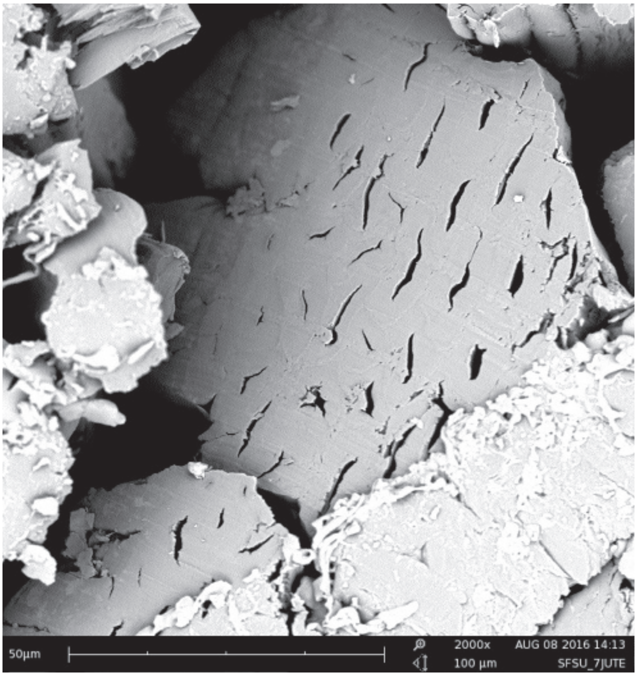


Figure 1.28 Magnified (2000×) image of a fiber bundle depicting jute fibers having large lumen opening in the center of each fiber.

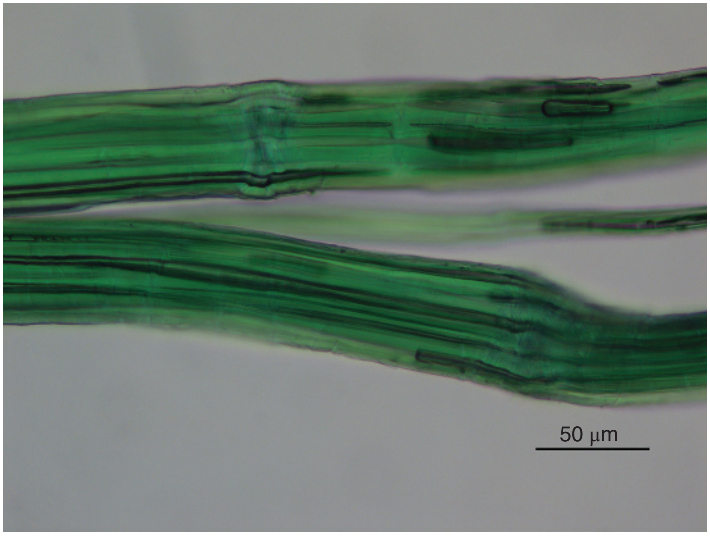


Figure 1.29 Longitudinal view of jute fibers using compound microscope – nodes are more visible than with the use of SEM.

the right. In the case that the fibrils are oriented to the right (or also referred to as having the S-twist), the fiber is flax, nettle, or ramie, and if the orientation of the fibrils is to the left (or also referred to as having a Z-twist), the fibers are hemp or jute [17].

To further distinguish, for example flax and nettle (both of which would have the S-twist fibril orientation), a crystal test is recommended. For this test also, PLM is recommended with a mounting medium – galvanol. During this crystal test, an examiner would be able to detect calcium druses (cluster of crystals) or solitary crystals. Calcium druses occur in nettle, ramie, hemp, and jute, and solitary crystals occur in hemp and jute. Flax fibers have no crystals present.

1.2.8 Bast Fiber in Its Historical Context

As mentioned earlier, bast fibers such as nettle, jute, and hemp are not used today in clothing on a large scale. However, the identification of them becomes very important in historical clothing. The earliest textiles are not only believed to come from plants such as flax but also from plants with wild origins [22]. As a matter of fact, there is more and more evidence found that nettle fibers were used for clothing. In some instances, historians believed archeological items were made of flax (because the characteristics of bast fibers are so similar), but later rediscovered that those fibers were actually made out of nettle. This misidentification occurs every so often, but with new methods for identifying textile fibers such as before mentioned fiber fibrillar orientation or detection of crystals, we can more precisely understand the use of nettle fibers. One instance is the Bronze Age 2800-year-old Lusehoj burial site in Voldofte, Denmark, where fabric (which was wrapped around a deceased body) was identified as nettle, but previously thought of as flax [29]. The correct fiber identification helps us understand the importance of nettle in clothing thousands of years ago. Because the buried body was wrapped in nettle fiber, it gives the historian an idea that nettle fibers must have been special in some way and might have been considered a luxury fiber [29]. In another similar instance of a Norwegian Viking burial ship that dated back approximately 834 BCE, a cloth from flax plant was found at this site, which was later re-examined and proven to be made out of nettle plant [22].

1.3 Leaf Fibers

Leaf fibers come from plant leaves and leaf stalks. Although they are not used in textile products to the same extent as seed and bast fibers, they can still be found in many interior design products such as rugs and home decor. Leaf fibers are stiffer and coarser than bast and seed fibers. There are three main leaf fibers: sisal, henequen, and abaca. Sisal and henequen fibers are both derived from Agave plants. The Agave family also hosts a plant that is used for making tequila.

1.3.1 Sisal

Sisal fibers are derived from the leaves of Agave sisalana plant, which originates in Mexico. The Aztecs and Mayans used sisal fibers for garments and used the spines of the plant as needles, thus came the name for sisal as "needle and thread plant" [30, p. 204]. The coarse texture of sisal fibers constitutes their use mainly used for rope, baskets, and nets. The longitudinal view of sisal fibers is somewhat cylindrical [7], but it does not show any distinguishing features [19]. The longitudinal view has some indentations, and some fibrils can be seen on its surface. The cross-section of sisal fibers is more pronounced, and the fibers have distinguishing characteristics than those in their longitudinal view. The fibers have polygonal shape with a pronounced circular to oval lumen [19]. Sisal fibers, just like coir fibers, have a large empty lumen and a thin wall. The fibers come in bundles. The size of the fiber can be a good fiber indicator as sisal fibers are larger than other seen or bast fibers. The diameter of sisal fibers is between 100 and 300 μm, and the length ranges between 0.6 and 1.5 mm [31].

1.3.2 Henequen

Henequen fibers are obtained from the Henequen plant (Agave fourcroydes), which is in the same plant family as sisal. Henequen is also an ancient fiber of the Mayans and is native to Yucatan, Mexico. Henequen fibers are similar to those of sisal longitudinally. In cross-section, the shape varies as it changes from bean-like to rounded [7]. Henequen fibers are also used for robes and twine; however, they are coarser than sisal fibers and therefore not considered as of high quality as sisal.

1.3.3 Abaca

Abaca fibers are taken from the leaves of banana-like plant called Musa textilis. The origin of the plant is the Philippines and therefore is sometimes referred to as Manila hemp. The longitudinal view shows both fibrils and some cross-markings. Although cross-markings are believed to be rare [7]. The cross-sectional view also has a large lumen as sisal fibers, but abaca does not have as thin a wall as sisal fibers. Abaca fibers in cross-section are round and not polygonal as sisal fibers. Abaca fibers also come in bundles. When comparing the bundles of abaca and sisal fibers, sisal fibers have bundles of crescent form, and abaca fibers have bundles of oval contour [19]. Abaca is considered to be the strongest of all natural fibers [7]. It is resistant to water, and therefore, it is used for marine ropes and tea bags. The fiber diameter and length of abaca fibers are smaller than those of sisal as the diameter ranges from 14 to 50 μm and the length ranges from 2.5 to 13 mm [32].

1.3.4 Pineapple Leaves

A novelty leaf fiber worth noting comes from pineapple leaves grown in the Philippines. It is considered to be sustainable because the pineapple leaves are a natural waste product. It has been marketed under a Piñatex™ and offered as a sustainable alternative to leather. The fabrication is a nonwoven textile material coated with polylactic acid (PLA) for the feel and appearance of leather-like material. PLA is also considered to be an environment friendly material because it is derived from renewable agricultural sources such as corn starch or sugarcane. It is a synthetic biodegradable polymer. Piñatex fabrication promises to replace other nonenvironmentally friendly alternative such as polyvinyl chloride. Preliminary microscopic examination of pineapple leaves is that in the longitudinal view some indentations and some fibrils can be seen on its surface.

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