3.1 Common Natural Fibers

3.1.1 Vegetable fibers - seed, and fruit fibers that are unicellular and used as individual fibers

3.1.1.1 Cotton

Gossypium sp. Unicellular seed hair- Formed by the elongation of a single epidermal cell of the cottonseed (8). Cotton in its raw state is composed primarily of cellulose with small quantities of wax and fat. Fibers appear ribbon-like, twisted, form convoluted flattened tubes and have a diameter from 8-33 microns and a length of approximately 1.7 cm. (Note:overall size varies with source and maturity) (5). Cross- sectional shape is U-shaped or ellipsoid. Can be distinguished by its lack of extinction under cross-polars (15,10).

Mercerization Process Process where raw cotton is placed in 18% NaOH. A very strong swelling of cotton fiber occurs and the cellulose is modified into another crystalline configuration. This mercerization process (invented by John Mercer in 1844) is commercially carried out with stretched yarns. This treatment causes permanent increase of the diameter of the fiber and a straightening out of its convolutions (4). Huber's reagent 20 grams iodine in 100ml of a saturated solution of potassium iodide in water (4).

3.1.1.2 Kapok

Ceiba pentandra and Bombax sp. Unicellular hairs that occur in the pods which make up the fruit of the plant (10). "There are two sources of kapok both obtained from the seedpods of the silk cotton trees belonging to the botanical family Bombaceae: Java and Indian kapok" 10. The fiber is known as vegetable down or bombax cotton (6). Fibers are soft, smooth, cylindrical, hollow, thin walled, lustrous and range from transparent colorless to yellowish-brown in color (5,6). Fibers frequently are bent over themselves and taper at one end with a bulbous base with net-like thickening (10). Kapok fiber has a diameter of 20 microns and an average length of 2.0 cm. The cross-section of the fiber appears circular to oval with a wide lumen and very thin wall (9). When mounted in water fibers show a characteristic series of air bubbles. This accounts for their use in stuffing, cushions, mattresses, and life jackets (9). The walls of the kapok fibers consist of highly liquefied cellulose and will give a yellow/brown color with Herzberg stain (9).

3.1.1.3 Coir

Cocos nucifera seed/fruit fiber from coconut. Is seen as a reddish mass contained between the outer husk (seed) of the coconut and the shell of the inner kernel (fruit). Principal sources are India and Sri Lanka. The ultimate (individual) fibers are short (less than 1 mm long) and the edges of some fibers show a distinct wavy outline. The fibers contain round stegmata in the ash that are particularly characteristic

(10). The best quality fibers are used for ropes and mats and lesser quality coarse fibers are used for stuffing mattresses and brush making.

3.1.2 Bast fibers

"Stem fibers"; "soft fibers". "Bast" is synonymous with phloem, the conducting tissue of vascular plants (10). The bast or phloem (outer side of' stem) contains the bast fiber bundles that are the source of the commercial fiber (8). Bast fibers are long multi-celled fibers from Dicotyledonous plants; contain cellulose and can have some lignin, give strength to the stalk, used as a fiber bundle composed only of numerous individual fibers and/or as individual fibers (6,13). These fiber cells do not contain elements of transportation tissue like hard fibers (13). Bast fibers are utilized in the form of full length bast bundles with two exceptions, one being flax. Flax fibers are separated during the spinning process for fine yarn (6).

3.1.2.1 Flax

Linum usitatissimum L. (linen) Obtained from the stem of the flax plant. Used to make linseed oil. It is a long, smooth fiber that has a cylindrical shape with a diameter of 20 microns and an average length of 3.0 cm (9). "Its color is usually off-white to tan and due to it's natural wax content, flax has excellent luster" (11). It is claimed to be the strongest of the vegetable fibers and is highly absorbent evaporating moisture quickly (11). "The number of fiber bundles within the stem ranges from 15-40 and each of the individual bundles contains from 12-40 ultimates"(10). Fiber shows the presence of transverse dislocations that form an "X" or "V" (8). The walls of these fibers have a spiral fibrillar structure(10). Cross-sectional shape shows polygonal and slightly rounded outline. When stained with Herzbergs, fiber has red/brown color with distinct yellow- colored lumen (9). Let sit 5-10 minutes and find a lighter stained area to examine. Usually this allows you to see the golden lumen more vividly. When processed the fiber is referred to as linen and is used for tablecloths, napkins, twine, and fishing tackle (11)

Flax general characteristics -some taken from McCrone (5).

- colorless to pale yellow
- smooth rounded polygonal cross section averaging 17 microns
- nodes appear like X's, V's and Y's with some thickening
- extinction is parallel for single fibers, bundles show none and incomplete at the nodes
- 2-10 fibers common
- very narrow and distinct lumen
- bamboo like
- Phloroglucinol- very little pink staining, if any
- Herzbergs -red/brown with distinct golden lumen

3.1.2.2 Jute

Obtained from the bast of two plants Corchorus capsularis and Corchorus olitorius, of the botanical family Tiliaceae. Main source is Bangladesh and India (2). Natural Jute has a yellow to brown or gray color sometimes with a pink tinge and a silky luster (2,11). Fiber lies along the length of the plant stem and is composed of more than one layer. Commercial fibers are 1.5-3 meters long, cross-section shows from 6-20 (sometimes as many as 50) single thick-walled polygonal cells (ultimates) each containing a central lumen or canal; longitudinal view shows lumen that can show considerable variation (thin & broadens) with tips that are pointed 10. Fibers have a high lignin content that is indicated by its red color when reacted with phloroglucinol (7,8). "Jute is utilized in its bast form and never separated down to the elementary fiber" (4). Used in the manufacture of linoleum and carpets for backing or fabric base, burlap bags and in textiles for interiors such as wall hangings, draperies and wall coverings (11).

Jute general characteristics - some taken from McCrone (5)

- transparent, colorless to pale yellow fibers
- straight smooth cylinders with some nodes -not conspicuous
- lumen is irregular with constrictions
- both ends taper to points
- fiber ultimate is 15-25 microns
- appears as bundles, seldom separated
- cross section polygonal with sharp angles
- shows parallel extinction except at nodes
- faint cross markings are viewable under cross polars
- appears as a complexity of many fibers
- high lignin content -red with phloroglucinol

3.1.2.3 Ramie

Boehmeria nivea Ramie called rhea and china grass, it is obtained from a tall shrub grown in Southeast Asia (11). The fiber has a long ultimate (mean of 15.0 cm) and varies in diameter from 25-75 microns. They are thick walled, have a flattened cross section and there is considerable variation in the cross-sectional area of the individual ultimates. Fiber ultimates show cross markings and longitudinal striations are frequent (10). Longest single plant fiber cell known. Fibers can almost be identified by its diameter alone that can be up to 80 microns (4). Fibers have a permanent luster and take dyes well; they are affected little by moisture (11). Ramie is used as filling yarn in woolen fabrics and is also used in rope, twine, and nets(11).

Ramie general characteristics - some taken from McCrone (5).

- transparent and colorless cylindrical fibers
- nodelike ridges, longitudinal striations and no twisting
- thickness of 25-80 microns with 40 average
- length 6-64cm with 14 cm average
- single longest plant fiber cell known

- extinction is parallel except at the nodes
- well-defined lumen
- has cross-sectional shape similar to cotton with obvious radial lines from lumen (4)
- lumen is flattened, elongated, irregular or crescent (2)
- dislocations are frequent with many cross markings (sometimes difficult to see)

3.1.3 Structural fibers

"Leaf fibers" ; "hard fibers" .Obtained from leaves, leaf stalks and other parts of Monocotyledonous plants; used as complete vascular bundles composed of numerous individual fibers plus other structural materials from the plants (4). "The vascular bundles consist of transportation tissue, vessels etc., surrounded by a thick sheath of fiber cells" (4). Fibers contain more lignin than cellulose 13. Note: the difference between hard fibers and the soft fiber from the stem of Dicotyledonous plants(bast fibers) is that the latter contain only the fiber cells, without elements of transportation tissue. (13).

3.1.3.1 Sisal

Agave sisalana Perrine. Is obtained from the leaves of Agave Sisalana Perrine, plants native to Central America, and now cultivated in other parts of the world (9,10). The fibers are polygonal in outline with a rounded polygonal lumen. Fibers contain peculiar spiral vessels which are characteristic of sisal (4,8). Transparency of the fibers can be improved by placing fibers in methyl salicylate for several days 8. Sisal is distinguished from abaca by Billinghames's test. This test was devised by Swett for the differentiation of abaca (manila) from other fibers used in ropes (10). Sisal's main use is in the production of twines, cordage and ropes, sacking, carpeting and other coarse fabrics. Also used in papermaking. The fibers from henequen (Agave fourcroydes Lemaire), resemble sisal very closely and are often termed as sisal (10)

Sisal general characteristics - some taken from McCrone (5)

- yellow/brown fibers with some possible pink tinge
- occur in tight bundles
- smooth looking
- rounded tapered ends and not pointed
- fiber ultimates are 20-32 microns wide and 1.5-4.0 mm long
- fiber does not show extinction
- note the presence of very characteristic spiral vessels which look like a backbone (show negative sign of elongation)
- polygonal cross-section
- large lumen 1/2 to 1/3 times cell wall thickness .
- often crystals of calcium oxalate are present on the surface of the fiber
- light pink with some darker red/pink areas

3.1.3.2 Abaca (manila hemp)

Musa textilis Nee. The fiber, is obtained from the leaf sheaths of the abaca plant, which is cultivated mainly in the Philippine Islands (10). Their main use is in cordage, rope, twine, netting and broom making (4). The fiber is cream to yellow in color with some faint luster and some possible pink tinge (2). A characteristic of abaca is the stegmata (silica cells) which are found near the vascular bundles and appear as rectangular cells with a central depression (2,4). Stegmata are present in the living plant in longitudinal files adjacent to the fibers. They vary in shape and are useful in identification (10). Some say they resemble a "string of pearls" (9). Billinghame's test is often used for differentiating abaca (manila) from other cordage fiber (10).

Abaca general characteristics - some taken from McCrone(5)

- pale yellow fiber with some black lines and some possible pink tinge
- do exam in glycerin
- dislocations are frequent
- cross markings are rare and never evenly spaced
- wide lumen sometimes 2-8 times cell wall thickness
- diameter range from 14-50 microns and 1-15 mm in length (5)
- cross-section is oval to rounded polygonal
- silica cells (stegmata) are found near vascular bundles

3.1.4 Tests, Stains, & Preparations

3.1.4.1 Billinghame's

This test devised by Swett for the differentiation of Abaca (manila) from other fibers used in rope manufacture has certain disadvantages. These are the uneven staining effect, the difficulty in distinguishing at a glance between the colors produced, and the tendency of the colors to fade. The modified method of Billinghame's produces both greater color differences and more stable colors. The method of applying Billinghame's test is as follows.

- Wash the sample with methylene chloride to remove oil and allow it to dry.
- Boil the sample in 5% nitric acid for 5-10 minutes.
- Wash out excess acid with water and immerse the sample in cold 0.25N sodium hypochlorite for 10 minutes.
- Remove the sample and dry it.

Abaca (manila) assumes an orange color, whereas sisal and other leaf fibers are stained pale yellow color (10)

3.1.4.2 Drying-Twist Test

3.1.4.2.1 Principle

If a wet flax fiber is held at one end and allowed to dry, the free end, directed towards the observer, will be seen to move in a clockwise direction. Hemp fibers under similar conditions follow a counter-clockwise movement. This test may be applied to material at any stage of manufacture and is successful even with fibers that have been mercerized.

3.1.4.2.2 Apparatus

- A pair of forceps with fine tip.
- A hot plate or any other source of low temperature heat with a dark background.

3.1.4.2.3 Conditions of test

When examining the yarn or cloth, in the latter case after separating the warp and weft, cuttings about 25 mm long are taken from various places in the material in such a way as to obtain representative sampling. The cuttings are soaked for a few minutes in water and then, with the aid of forceps, individual fibers are withdrawn and held over the hot plate in order to observe the direction of the twist on drying.

3.1.4.2.4 Precautions

As far as possible single fibers should be used and examined. Small bundles of fibers, however, can be examined, provided that sufficient time is given over the hot plate to ensure that the drying twist has set in (10). Refer to chart for results of this test.

3.1.4.3 Herzberg's

One of the most widely used reagents on cellulose which stains blue-violet, while lignocellulose stains yellow-brown. The more lignocellulose is present the yellower the fiber (4). Herzberg's stain (or zinc chloroiodine reagent) can be prepared by the following formula. Dissolve 20 grams of zinc chloride in 10 ml of water; add 2.1 grams of potassium iodide and 0.1 gram of iodine in 5 milliliters of water. Add a leaf of iodine (1). Refer to chart for the results of this test.

3.1.4.4 Maceration of vascular bundles (fibers)

The commercial (technical) bast fiber can be broken down into its elementary (ultimate) fibers by treatment in the laboratory with various chemicals (maceration) (4). A good technique, per Skip Palenik, is as follows:

- Right before use, mix equal parts of glacial acetic acid and 30% H2O2 (hydrogen peroxide); wear goggles and gloves.
- Insert fibers in test tube with the above mixture and place within a boiling water bath. EXTREME CAUTION: Make sure H2O2 mixture does not completely evaporate as it may be explosive if heated to dryness.
- Check periodically. Depending on the fiber the process can take from 3 to 24 hours. The process is dissolving away the lignin holding the fiber ultimates together. Fiber will be white and translucent when done.
- Pour off spent solution. Rinse fibers in test tube several times with distilled water. Cells will loosen and you can tease the strands apart with dissecting needles or forceps on a glass slide. Another method would be to stopper the test tube and shake the fibers in the last distilled water rinse. Remove separated fibers with a glass pipette, place fibers on glass slide and evaporate to dryness on hot plate (14)

3.1.4.5 Phloroglucinol

The test detects the degree of lignification among plant tissues. Lignified plant tissues will turn a bright wine red (7). A 2% solution of' phloroglucinol in alcohol is added to an equal amount of concentrated hydrochloric acid. The mixture is stored in an amber dropper bottle and can be useable for years (7). Lignified fibers such as jute (unbleached) show the highest degree of lignification and therefore are stained a bright red color (7). Other fibers such as sisal and abaca are moderately lignified as indicated by a pink color (8).

3.1.5 Glossary

Dicotyledons vs. Monocotyledons -Two classes of Angiosperms are the Monocotyledons and the Dicotyledons. Monocotyledons have one seed leaf (cotyledon) that is produced at germination and the Dicotyledons have two seed leaves. Another difference is in the anatomy of these plants. The Monocots have vascular bundles that are scattered, whereas the Dicots are arranged in a ring (12).

Dislocations -this term "dislocations" and the first descriptions of these displacements in sclerenchyma cells are attributable to Von Hohnel (1884), who wrote of "ring markings" which occur as a result of "tension in the tissues" (2).

Extinction An examination of fibers or other crystalline substances that are placed between two crossed polars under a microscope, noting their appearance as the stage is rotated. Fibers that are rotated and turn dark are described as being at an extinction point. In birefringent fibers, this is the point where one of the principal refractive indices of the fiber is parallel to the vibration direction of the polarizer or analyzer (5).

Lumen- "The total space within the cell wall" (4). The lumen (or central core of the fiber cell) can be prominent, indistinguishable, wide, narrow, continuous, of even or uneven width and interrupted (9).

Ultimates- Individual fiber cells of the commercial fibers are often referred to as elementary or ultimate fiber cells (4).

3.1.6 See Appendix 3.1 A: Summary of Characteristics of Common Natural Fibers

3.1.7 References

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