TEXTILE RAW MATERIALS

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Dedication

This work is dedicated to the authors, and their families for moral support during the writing of this book.
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1. Introduction

1.1 Fiber Introduction
The term “textile” was traditionally used to define fabrics and the steps involved in manufacturing of woven fabrics. For a longer period, it involves the following:

i) Staple fibers and filaments used in the manufacturing of yarns, woven, knitted and nonwoven fabrics.
ii) Yarns of different types made up of natural or man-made fibers.
iii) Fabrics of several categories and other textile products made directly from fibers or from yarns.
iv) Home textiles, medical textiles, protective textiles, and apparels are manufactured from the above which retain the core properties of textiles like mechanical properties, flexibility, and integrity of structure and drape of the fabrics.

Most of the textile fabrics exhibits planar structures manufactured by interlacing, looping or entangling yarns or fibers in a discrete manner. In a broader term, yarns are continuous strands textile fibers. These fibers must exhibit the required physical and chemical properties that are necessary of the end applications. So, textile fibers can be defined as the basic physical structures or elements used in textile products. The structure of every fiber consists of several individual long molecular chains having some specific chemical structure [1].

1.2 Fiber classification
Fibers are categorised into two main classes, natural and man-made fibers. The fibers from natural resources like plants, animals that do not need fiber formation or regeneration are categorised as natural fibers. Natural fibers include the cellulosic fibers like cotton and flax, the mineral fiber such as asbestos and the protein fibers like silk and wool. Man-made fibers are formed by chemical synthesis followed by fiber extrusion or the naturally available polymers have been dissolved in chemicals and reproduced by passage through a spinneret to extrude fibers. Fibers formed by chemical synthesis are named as synthetic fibers, while fibers regenerated from natural polymers are named as regenerated fibers. So, all fibers natural origin are provided by nature in ready-made form. But man is involved in the manufacturing processes of synthetic fibers and regenerated fibers, due to this reason categorised as man-made fibers.
1.3 Natural fibers

Natural fibers are of three types.

- Natural fibers of vegetable origin.
- Natural fibers of animal origin.
- Natural fibers of mineral origin.

1.3.1 Natural fibers of vegetable origin

The natural fibers that fall in the category of vegetables are majorly composed of cellulose. This element is made of sugars and starch that is generated by the plant with the help of water and carbon dioxide, riveted through its leaves. Fibers in form of bundles are held together with the help of natural resins and gums that are present in different parts of plants like leaves, stem etc. The cellulosic fibers can be divided into the following categories based on the parts of plants from they are extracted [2] [3].

- Stem fibers. They are also known as bast fibres. Originated from the bundles of fibers in the inner side of bark of the stem, in plants that are produced by two – seed leaves (dicotyledonous).
- Fibers from the Leaves. Fibers that are extracted from the leaves, they are present lengthwise in the plants that are formed by one seed leave (monocotyledonous).
- Fibers from Fruits and Seeds. Comprises of the hair from seeds and the flosses.
1.3.2 Natural fibers of animal origin
The share of animal fibers in the textiles is 7 per cent of the total volume of textile fibers. They provide a minor part of the textiles of total world production. Despite of their limited production they have a vital role in textiles. Some fibers of this origin are as follows.

- Wool fibers and hair fibers. These fibers are extracted from the animals having fur, these fibers are widely used as textile fibers. Wool is the most important textile fiber. It provides 90 per cent of the total animal fiber. The terminology wool is specifically used for the fibers extracted from sheep, while there are other hair fiber that are obtained from other animals. There is another major difference between them that is the long and coarser fibers that forms the outer layer are referred as hair, while the shorter and fine fibers that forms inner layer are called wool. All he hair and wool fibers are formed of keratin so their chemical structure is related, but they exhibit different physical characteristics such as length, shapes and fineness.

- Silk fiber. This fiber is spun in form of cocoon by silkworm. This natural fiber is of great importance as is the sole fiber that is found in form of a continuous filament naturally. The production of silk in all the textile fibers is very low i.e. 0.25 per cent of the total textile fibers. Despite of this fact it is a very important textile fiber and it is expensive when compared with other textile fibers [4].

1.3.3 Natural fibers of mineral origin
The natural fiber that falls in the category of minerals is asbestos. It is a set of silicate minerals that are present naturally. It is one of the strongest fibers that is found naturally. Basically, it is in the form of rock that has under gone rare experiences during its production. Rather than crystallization it is produced as fibers, firmly packed with each other due to which the rock represents a grainy construction. The asbestos rock looks a lot like wood, it is good resistant to heat and inflammable. Asbestos is used as fiber since ancient times. Mostly used as wicks of vestal virgin lamps. The Minerva lamp had wick made of Carpasian linen, made of asbestos that was extracted by mining in Cyprus, this linen was resistant to fire.

1.4 Manmade fibers
There are many naturally occurring long molecules that are thread like but could not fulfil the purpose of textile fiber. In most of the natural fibers like cotton, jute, silk and flax nature has performed the entire job for their production. But in many other cases, the fiber forming substance is present in a form that cannot directly be used as textile fibers. Such as cellulose contained by wood is bound together by lignin and some other gummy materials. In this case man has carried the job of converting the fiber forming substance to actual fiber that can be utilised as textile fibers. The rayon industry has developed on this principle, where nature has not created the materials as textile fibers but having the capacity to make them as textile fibers.

Moreover, man has established the techniques to manufacture the textile fibers independently. We can produce long chain molecules from very simpler chemicals. By using this technique, we have learnt to produce polyester and nylon. Novelty with these fibers is to get pre-determined characteristics as per required by end application [5].

Manmade fibers are categorised into two major groups, depending on the source for fiber forming materials. The categories are as followed:

- Regenerated fibers
- Synthetic fibers
The regenerated fibers are also known as natural polymer fibers, in which the fiber forming substance is obtained from natural sources. These are sub-categorised into following:

- Cellulose fibers
- Cellulose ester fibers
- Protein fibers
- Miscellaneous natural polymer fibers

The synthetic fibers are sub-categorised according to their chemical structure. Some of the commercially important synthetic fibers are as followed:

- Polyesters
- Polyamides
- Polyvinyls
- Polyurethanes
- Polyolefins

The modern synthetic fibers are often modifications of polymers or copolymers. Consequently, they will be considered as belonging to two or more sub groups.
2. Seed Fibers

2.1 Introduction
The most important and widely produced plant fiber is cotton fiber, which grows in the seed hair boll of cotton plants grown and cultivated in climates like U.S.A, China, Australia, Egypt, Pakistan and India. Cotton fibers are hairs on the seeds of the order Malvales plant, Malvaceae family, and genus Gossypium. Botanically, cotton fiber has for main species; hirsutum, barbadense, aboreum, and herbaceum. These four species contain many different varieties developed through breeding programs to form cottons with enhanced properties like fiber exhibiting greater length, strength, uniformity, rapid maturing, increased yields, and high resistance to insects and diseases.

Gossypium hirsutum, the most important variety was developed in the U.S.A, it is the cotton native to Mexico and Central America. Cottons from this specie provide over 90% of the current world production of raw cotton fiber. The staple lengths of this variety ranges from about 24 to 36 mm, and the fiber fineness ranges from 3.8 to 5.0 micronaire. The cotton fiber from Gossypium hirsutum is mostly used in apparel textiles, home textiles, and industrial textiles.

Gossypium barbadense, has been developed in South America and produced as Egyptian, American-Egyptian, and Sea Island cottons, which provides the longest staple lengths and specifically called as extra-long staple (ELS). Cottons from this specie provide about 8% of the current world production of raw cotton fiber. The staple lengths of this category is long and fine with a staple length greater than 35 mm and the fiber fineness is below 4.0 micronaire. Egypt and Sudan are the major manufacturers of extra-long staple cotton’s products in the world market. Pima cotton, which is also extra-long staple cotton, is a cross of Egyptian and American Upland strains and is produced in South America and in the western United States. The cotton fiber from Gossypium barbadense is used in applications like high-quality apparel, sewing thread, luxury fabrics, specialty yarns, and knitted yarns.

Gossypium aboreum and Gossypium herbaceum; commonly called as “Desi” cottons, and comprises of short staple cottons. These low-quality cotton fibers are the short staple cottons mainly cultivated in Pakistan, India, Bangladesh, Thailand, and Vietnam. The fibers from this specie has lower staple length and coarser micronaire values.

2.2 Classification of cotton fiber with respect to staple length
The staple length of cotton fiber is a significant factor for defining the overall quality of cotton fibers and it has a major impact on the end application of cotton fiber. Commercially available cotton is classified into following categories with respect to staple length:

<table>
<thead>
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<th>Sr. #</th>
<th>Variety of cotton</th>
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<tr>
<td>1</td>
<td>Very short staple</td>
<td>≤ 21</td>
</tr>
<tr>
<td>2</td>
<td>Short staple</td>
<td>22~25</td>
</tr>
<tr>
<td>3</td>
<td>Medium staple</td>
<td>26~28</td>
</tr>
<tr>
<td>4</td>
<td>Ordinary long staple</td>
<td>29~34</td>
</tr>
<tr>
<td>5</td>
<td>Extra-long staple</td>
<td>≥34</td>
</tr>
</tbody>
</table>
Famous varieties of Pak cotton fiber;

i) Abadgar-901
This variety has the highest effective length followed by Tarzen-1 and Sattari has lowest effective length [6].

ii) Tarzen-1
This variety exhibited the highest value of tenacity, and Nayyab-78 has lowest tenacity.

iii) MNH-93
The variety of cotton cultivated in the regions of Punjab province.

iv) Nayyab-78
The variety of cotton cultivated in the regions of Sindh province. This variety has the coarsest fibers.

v) Organic Cotton
Organic cotton is normally assumed as cotton fibers grown from non-genetically modified plants, the use of synthetic chemicals like fertilizers or pesticide is prohibited in the cultivation process of cotton fiber. Organic cotton helps to protect the surface and groundwater by eradicating impurities and toxic chemicals in surface runoff, reduce the risks of insect and disease, and eliminate the use of toxic chemicals in cultivation process.

vi) BCI Cotton
The Better Cotton Initiative was developed to create world’s cotton production better for the people who produce it, better for the sector’s future, and better for the environment its cultivation. BCI organization works under the theme of “Aid by trade”.

2.3 Harvesting and ginning
The processes of harvesting and ginning the cotton fibers have vital impact on the excellence of the cotton fiber. Harvesting time for cotton varies from region to region. Harvesting is the ending and most essential step in the manufacturing of a cotton crop as the crop must be harvested on time to avoid damage to the quality and reduction in yield. In developed countries like, the United States and Australia cotton crop is picked mechanically. But in less developed countries having lower labour cast, cotton crop is harvested manually and known as “hand picking”. Mechanically harvested cotton may have more trash and other impurities than hand-picked cotton. However, according to “Cotton contamination surveys” carried out by the International Textile Manufactures Federation (ITMF), the most contaminated cottons found countries where cotton usually is manually harvested or commonly said to be hand-picked, whereas some of the contamination free cotton can be obtained from the USA where cotton crop is machine harvested [3].

Harvested cotton crop contains the seeds attached to cotton fibers and trash also present in it, in this form it is transported to the ginning plants. Ginning process is categorised as the separation of the cotton fibers from its seeds and up to some extent removal of trash. Ginning operations, which are considered a part of the harvest, are normally considered to include conditioning (addition of moisture), seed-fiber separation (mainly focussed), cleaning (removal of trash), and packaging.
The packaging of bales, and their respective weight per bale varies from region to region and country to country [1].

The raw cotton passes through several cleaning processes before it is baled. As a result, the grower obtains valuable by-products that amount approximately to one-sixth of the entire income derived from the cotton plant. Cotton Linters are the short hair like fibers used in making regenerated fibers, Hulls are the outside portion of seed, rich in nitrogen, used as fertilizer. Inner Seeds are the seeds inside the hull gives cottonseed oil used in cooking and it also used in manufacturing of soap.
Table 2: Bale weight of cotton in different countries with their respective densities and harvesting periods

<table>
<thead>
<tr>
<th>Country</th>
<th>Harvest</th>
<th>Bale weight</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Average Kg</td>
<td>Range Kg</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lb Kg</td>
<td>Lb Kg/M3 Lb/Ft3</td>
</tr>
<tr>
<td>Mexico</td>
<td>June-Jan.</td>
<td>227</td>
<td>180-240</td>
</tr>
<tr>
<td>Guatemala</td>
<td>Nov.-March</td>
<td>227</td>
<td>220-236</td>
</tr>
<tr>
<td>Brazil</td>
<td>Aug.-Jan.</td>
<td>140</td>
<td>110-180</td>
</tr>
<tr>
<td>Argentina</td>
<td>Feb-June</td>
<td>220</td>
<td>195-250</td>
</tr>
<tr>
<td>Paraguay</td>
<td>Feb.-June</td>
<td>198</td>
<td>160-225</td>
</tr>
<tr>
<td>Columbia</td>
<td>July-Sept.</td>
<td>225</td>
<td>220-240</td>
</tr>
<tr>
<td>Greece</td>
<td>Sept.-Nov.</td>
<td>234</td>
<td>80-90</td>
</tr>
<tr>
<td>Spain</td>
<td>Sept.-Nov.</td>
<td>225</td>
<td>200-250</td>
</tr>
<tr>
<td>Uzbekistan</td>
<td>Sept.-Nov.</td>
<td>200</td>
<td>190-220</td>
</tr>
<tr>
<td>China Bale I</td>
<td>Sept.-Nov.</td>
<td>85</td>
<td>80-90</td>
</tr>
<tr>
<td>Bale II</td>
<td>Sept.-Nov.</td>
<td>200</td>
<td>190-210</td>
</tr>
<tr>
<td>India</td>
<td>July–Jan.</td>
<td>170</td>
<td>165-175</td>
</tr>
<tr>
<td>Pakistan</td>
<td>Sept.-Feb.</td>
<td>170</td>
<td>160-185</td>
</tr>
<tr>
<td>Turkey</td>
<td>Sept.-Dec.</td>
<td>217</td>
<td>190-245</td>
</tr>
<tr>
<td>Australia</td>
<td>Apr.-June</td>
<td>227</td>
<td>150-240</td>
</tr>
<tr>
<td>Iran</td>
<td>Oct.-Dec.</td>
<td>200</td>
<td>170-240</td>
</tr>
<tr>
<td>Syria</td>
<td>Sept.-Nov.</td>
<td>205</td>
<td>192-212</td>
</tr>
<tr>
<td>Egypt</td>
<td>Sept.-Oct.</td>
<td>327</td>
<td>290-345</td>
</tr>
<tr>
<td>Sudan</td>
<td>Jun.-April</td>
<td>188</td>
<td>185-191</td>
</tr>
<tr>
<td>South Africa</td>
<td>Apr.–May</td>
<td>206</td>
<td>170-240</td>
</tr>
</tbody>
</table>
2.3.1 Types of ginning
According to mechanical operations, the ginning process is mainly divided into two categories;

2.3.1.1 Saw ginning process
The saw ginning process includes saw toothed roller and the narrow slits, fibers are catch by the teeth of rollers and pulled through narrow slits. Seeds have bigger size, so unable to pass through slits and detached from fibers. The detached longer fibers from this process are known as lint. Shorter fibers are still attached to the fibers, which are detached by another gin. The process of saw ginning can be understood by Fig. These shorter fiber are known as linters, used as a raw material for the manufacturing of regenerated cellulosic fibers and have applications as fillers of pillows, blankets, upholstery, etc.

![Gin Operation](image)

Figure 2: Schematic diagram of Saw ginning operation
(Courtesy by Levadia's Cotton Gin & Oil Mill house, Greece)

2.3.1.2 Roller ginning process
The roller ginning process includes a wooden roller covered with leather discs and knife. The gauge between the roller and knife is adjusted so that it allows fibers to pass through it but seeds due to their bigger size cannot pass and thus separated from the lint. The ginned cotton is packed in bale form and dispatched to spinning mills for further processing. Fig shows the process of roller ginning process.
Figure 3: Schematic diagram of Roller ginning operation

Seed cotton uploading system

Seed cotton pre-cleaning

Drying system

(1 or 2 Stages)

Seed cotton cleaning

Gin Stand

Cottonseed to storage

(1 to 3 Stages)

Lint cleaners

Bale press

Bale cotton to storage
2.4 Chemical constituents of cotton fiber

After the processes of ginning and mechanical cleaning, the raw cotton fiber contains 95% cellulose. The cellulose structure of cotton fiber is a linear polymer of β-D-glucopyranose. The noncellulosic components of the fiber are found mainly in the primary cell wall, in the cuticle, and in the lumen. The noncellulosic components are mainly amino acids, proteins, nitrogenous compounds, waxes, pectic parts, sugars, inorganic salts, and minor quantity of pigments (actual % of each constituent is given in Table). The formulae of cellulose is as follows;

Variations in quantity of components arises due to differences in environmental conditions of the region in which it is cultivated, fiber's maturity, and variety of cotton. Environmental conditions include soil, climatic conditions, etc. By using different chemical treatments, the noncellulosic parts can be removed, after that the cellulose content of the fiber can reach to the values of over 99%. These chemical treatments involve processing the cotton fiber with selective solvents to remove the noncellulosic materials. For example, waxy parts can be removed by treatment selectively with nonpolar solvents like hexane and chloroform, or non-selectively by heating the cotton fibers in a 1% sodium hydroxide solution.

Table 3: Chemical constituents of cotton fiber

<table>
<thead>
<tr>
<th>Sr. #</th>
<th>Constituents</th>
<th>Typical %</th>
<th>Range %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cellulose</td>
<td>95.0</td>
<td>88.0–96.0</td>
</tr>
<tr>
<td>2</td>
<td>Protein (% N×6.25)</td>
<td>1.3</td>
<td>1.1–1.9</td>
</tr>
<tr>
<td>3</td>
<td>Pectic substances</td>
<td>0.9</td>
<td>0.7–1.2</td>
</tr>
<tr>
<td>4</td>
<td>Ash</td>
<td>1.2</td>
<td>0.7–1.6</td>
</tr>
<tr>
<td>5</td>
<td>Wax</td>
<td>0.6</td>
<td>0.4–1.0</td>
</tr>
<tr>
<td>6</td>
<td>Total sugars</td>
<td>0.3</td>
<td>0.1–1.0</td>
</tr>
<tr>
<td>7</td>
<td>Organic acids</td>
<td>0.8</td>
<td>0.5–1.0</td>
</tr>
<tr>
<td>8</td>
<td>Pigment</td>
<td>Trace</td>
<td>–</td>
</tr>
<tr>
<td>9</td>
<td>Others</td>
<td>1.4</td>
<td>–</td>
</tr>
</tbody>
</table>

2.5 Growth rings of cotton fibers

After completion of lengthwise growth, the maturity of cotton fiber starts to increase by improving its internal structure. Cellulosic layers begin to be deposited one after another to the membrane. With the passage of everyday, cotton fiber gets a new layer of cellulose. The cross-section of cotton fiber is very much like the growth rings of a tree, but the only difference is that in a tree the outermost layers are the latest ones and in cotton fiber innermost layers are the latest ones. The growth rings of cotton fiber correlates to its growth and deposition of cellulose. Each ring of cotton fiber comprises of two secondary layers, first layer solid and compact one but the other layer has porous structure. In figure layers of cotton fiber are shown clearly.
When cotton plant’s boll open, the water content present in it evaporates from the cotton fibers. Before moisture evaporation fibers are circular in cross-section have tube like appearance. And moisture evaporated from the fibers, they get dried and cell wall collapse. It gets a ribbon like structure that is like inner tube of a bicycle when air has been removed. Immature cotton fibers have partially developed primary wall shown in figure and on contrary the mature cotton fibers have fully developed primary wall shown in figure. The immature cotton fibers can bend and tangle more easily, so these fibers are the cause of entanglements called as nep. These nep effect the appearance of fabric after dyeing, and appeared as undyed spots.

2.6 Structure of cotton fiber
The cotton fiber is single cell that has collapsed into a ribbon like structure of cellulose as it dried out. The matured fiber can also be recognised by the convolutions which are important characteristic of cotton. The longitudinal view of cotton fiber shown in (figure) reveals the convolutions in the cotton fiber. But cotton from different variety has different number of convolutions in it. In 25 mm of a cotton fiber, the Island cotton have 300 convolutions, Indian 150,
Egyptian 230, American 190, and Brazilian 210. The cross-sectional view of cotton fiber is oval and bean like shown in (figure 7).

Figure 7: SEM image, longitudinal view of cotton fiber

2.7 Cotton grading and various quality parameters
Many of the cotton varieties are being cultivated in different regions of the world, every variety differ in quality parameters of cotton fibers. The grading of all these cottons is an important task but difficult as well. The grading process has its own significance to make the right choice to produce different qualities of yarn having wide difference in their end applications. The traditional way for the classification is “classer” grading, which needs experience and personal skills. Classer grading takes note of the staple length, the colour of fiber, and impurities in the cotton fibers.

2.8 Physical properties of cotton fibers
In modern techniques, the most widely adopted is the equipment made by USTER® Technologies, called as USTER HVI. It can measure multiple quality parameters of cotton fiber, the spinning consistency index reflects the overall quality grading of cotton fiber. The other instrument used for fiber testing is advanced fiber investigation system called as USTER AFIS. Following are the important physical properties of cotton fiber.
### Table 4: Comparison of parameters measured by USTER HVI and USTER AFIS

<table>
<thead>
<tr>
<th>Parameters Evaluated by <strong>USTER HVI</strong> (High Volume Investigation)</th>
<th>Parameters Evaluated by <strong>USTER AFIS</strong> (Advanced Fiber Investigation System)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Upper Half Mean Length (UHML):</td>
<td>1) Nep (Count per gram):</td>
</tr>
<tr>
<td>UHML could be defined as average length of the longer (upper) half fibers in the sample checked. Its unit will be inches or millimetre. Maximum length of 65 mm can be seen for Sea Island fiber, whereas as linters could be 6 mm.</td>
<td>It is the number of entanglements of fibers in the cotton sample.</td>
</tr>
<tr>
<td>2) Mean Length:</td>
<td>2) Nep Size:</td>
</tr>
<tr>
<td>Average length of all the fibers in the sample being tested. Its unit will be inches or millimetres.</td>
<td>It is the size of the total neps in the cotton sample and expressed in µm.</td>
</tr>
<tr>
<td>3) Uniformity Index (UI):</td>
<td>3) Seed Coat Nepes (Count per gram):</td>
</tr>
<tr>
<td>It is also defined as Length uniformity, and it is the ratio between the average length and the upper half mean length (UHML) of the fibers. It is described in percent.</td>
<td>It is the number of the fragments of cotton seeds in the sample that still have some fibers attached.</td>
</tr>
<tr>
<td>4) Short Fiber Index (SFI):</td>
<td>4) Seed Coat Nep:</td>
</tr>
<tr>
<td>Amount of Fibers in percent that are less than 0.5 inch (12.7 mm) in length.</td>
<td>It is the size of the total seed coat neps in the cotton sample and expressed in µm.</td>
</tr>
<tr>
<td>5) Strength:</td>
<td>5) Mean length by weight:</td>
</tr>
<tr>
<td>It is defined as the force in grams required for breaking a bundle of fibers having one Tex unit size. It is expressed in Gram/Tex. (Normal range of strength is 25~45 grams per tex)</td>
<td>It is the average fiber length of all the cotton fibers in a cotton sample computed on a weight basis and expressed in inches or millimetres.</td>
</tr>
<tr>
<td>6) Elongation:</td>
<td>6) Upper Quartile Length by weight:</td>
</tr>
<tr>
<td>The average length of distance to which the fibers extends before breaking. It is expressed in percent. (Normal range of elongation is 5~10%)</td>
<td>It is the length of the longer 25% of all fibers in a cotton sample on weight basis and expressed in inches or millimetres.</td>
</tr>
<tr>
<td>Moisture:</td>
<td>7) Short Fiber Content by weight:</td>
</tr>
<tr>
<td>Amount in percent of water (H₂O) which is present in the sample being tested. Moisture regain of cotton fiber is 8.5%</td>
<td>The percent of all fibers in a cotton sample that are shorter than 0.5 inch or 12.7 mm on weight basis.</td>
</tr>
<tr>
<td>8) Reflectance (Rd):</td>
<td>8) Mean length by number:</td>
</tr>
<tr>
<td>This value expresses the whiteness of the light reflected by the cotton fibers. It corresponds to the reflectance (Rd) in the Nickerson-hunter</td>
<td>It is the average fiber length of all the cotton fibers in a cotton sample computed on a number basis and expressed in inches or millimetres.</td>
</tr>
<tr>
<td></td>
<td>9) Upper Quartile Length by number:</td>
</tr>
<tr>
<td></td>
<td>UQL is defined as the length of the longer 25% of all fibers in a cotton sample on number basis and expressed in inches or millimetres.</td>
</tr>
</tbody>
</table>
9) Yellowness (+b):
It is a measure of the yellowness of the fiber and is based on the Nickerson-Hunter scale. Cotton ranges from 4 to 18.

10) Colour Grade (C Grade):
Reflectance (Rd) is used in conjunction with the yellowness (+b) to determine the instrument-measured colour grade of cotton.

11) Trash Count:
It is a measure for the trash of cotton. It is the number of trash particles measured on the surface of the sample.

12) Trash Area:
The value is also a measure for the contamination of cotton. It indicates the contaminated area in comparison to the total area of the sample measured.

13) Trash Grade:
Classer's leaf grade, it depends upon Trash area (%) and ranges from 1 to 8.

14) Micronaire (Mic.):
It is the fiber fineness. A sample of fibers having constant weight is tested by passing air through it and the drop-in pressure is recorded then. It is expressed in µg/inch.

15) Maturity Index:
It is a relative value calculated from other HVI measurements, such as micronaire, strength & elongation. It indicates the degree of cell wall thickness in a sample.

10) Short Fiber Content by number:
The percent of all fibers in a cotton sample that are shorter than 0.5 inch or 12.7 mm on number basis.

11) 5 % length by number:
It is the length of the longer 5 % of all fibers in a cotton sample and expressed in inches or millimetres.

12) Fineness:
It is mean fiber fineness (weight per unit length) in millitex. One thousand meters of fibers having a mass of 1 milligram equals 1 millitex.

13) Maturity Ratio:
It is the ratio of fibers having 0.5 (or more) circularity ratio divided by the amount of fibers having 0.25 (or less) circularity.

14) Immature Fiber Content:
It is defined as percentage of fibers in a sample having a cell wall thickness covering less than 25 % of the full area.

15) Dust Count per gram:
It describes the smaller particles from the plant and simply dirt from the cotton field that sticks with the plant. (Particle size < 500 µm).

16) Trash Count per gram:
It is the general term for larger impurities containing particles from the cotton plant itself and other plants contaminating the cotton fields. (Particle size > 500 µm).

17) Total Trash Count per gram:
All particles removed by AFIS fiber individualizer, regardless of size, are counted and reported under this heading.

Effect of sunlight:
The oxidation of cotton fiber is enhanced in hot conditions and is greatly enhanced by sunlight. Cotton fiber also exhibits loss of strength as exposed to sunlight and +b also increased. The main damage to strength is done by ultraviolet radiations. Using some suitable dyes, the effect of sunlight can be minimised.
Effect of heat:

Cotton fibers burn very easily at normal atmospheric conditions. It is severely damaged at 240 °C even in few minutes of exposure. But cotton fiber’s +b value increases after several hours exposure to 120 °C.

Effect of age:

At proper and careful storage cotton fiber shows a very small loss in their strength so can be stored for a long time without any damage to its properties. But with improper conditions of storage, there will be loss in strength and increase in yellowness of cotton fibers.

2.9 Chemical properties of cotton fibers:

As discussed in the start of this chapter cotton fiber comprises of 94% of cellulose and remaining parts are non-cellulosic, most of the non-cellulosic parts are removed from cotton by treatments like scouring and bleaching. After these processes fiber consists of 99% cellulose and provide a whiter and stronger fibers. Waxy material in fiber act as lubrication in the process of spinning and amount of wax increases as immaturity increases. Following are the effects of different chemicals on cotton fibers;

Effect of acids:

Cotton is deteriorated by cold concentrated and hot diluted acid, which degrade the cotton fiber. But cold weak acids have no effect on cotton.

Effect of alkali:

Cotton fiber shows swelling in caustic alkali but this treatment is safe and not cause the degradation. It has excellent resistant against alkalis. Due to this reason, cotton fabrics could be washed repeatedly with soaps.

Effect of organic solvents:

Cotton has excellent resistance to normal solvents but is dispersed by concentrated H₂SO₄ and copper complexes cuprammonium hydroxide.

Effect of insect:

Cotton has high resistance to insects like moth grubs or beetles.

Effect of micro-organism:

Cotton has very poor resistance against bacteria and fungi. Mildew can attack and cause to weaken it. Damage can be avoided by the by scouring, because cellulose in pure form is less attractive food for mildew than starchy one. Mildew and bacterial attack on cotton is severe in hot and moist conditions.

2.10 Applications

Vast variety of products are made from cotton. The major products are made from the lint like textile and yarn goods, these textile yarns are then used to make different kind of fabrics including knitting and weaving. The linters a valuable source of cellulose used in the manufacturing of regenerated cellulosic fiber. Cotton hulls are used for fertilizer, fuel, and packing. Production of the chief by-product, cottonseed oil, has its own importance.

The major applications are like bath towels and robes, denim cloth, socks, underwear, T-shirts. Cotton also is used to make yarn used for knitting. Cotton yarns are incorporated with polyurethane filaments to get good elasticity and recovery properties. Products specifically made of Egyptian cotton have superior quality. These are a very few applications of cotton made products, it has several others as well.
3. Bast Fibers (Flax)

3.1 Introduction
Flax claimed to be the first fiber used for making textile, which is commonly known as linen. Linen mummy-cloth was used about 4,500 years ago. From the primeval textile fibers cotton, hemp, sunn, ramie and flax, the fiber known and used as early as 3400 B.C. in Egypt was flax. Linen curtains, From Egypt, during the Scriptural period the consumption of the fiber blowout to the zone comprising current Israel, Jordan, Iraq, etc. Further in Roman era it spread to England and France. As time passes it became popular in entire of Europe. The foremost fiber for clothing in western cultures was flax, as flax has a lower lignin amount. Impenetrable wadding lumps have use of flax to compete with glass and mineral wool building insulation.

It is derivative of the stanch of Linum usitatissimum; the temperature range is wide with reference to growth. The length of plant can be up to 4 feet, and flax fibers originate beneath the plant exterior in between timbered solid and cellular staple. To extract fibers from plant a process called retting is performed. Chemical retting includes the use of acids and bases; however, the process cost more compared to natural fermentation phenomena. The timbered staple is breakdown for the extraction of fibers, scotching is the next process that is elimination of the timbered material, next step is hackling which is also known as combing. The consequential fibers can be spun and size ranges to 12-15 inches.

3.2 The plant of Flax
The flax plant develops to a height ranging from 0.5 meter to 1.25 meters with a stalk diameter of 1.6 mm ~ 3.2 mm. Seeds are enclosed in small spherical balls, at the top of the stalks. Seeds of flax are used for the manufacturing of linseed oil. Flax plant is grown for both seed and the fiber, from which seed is used as food material and fiber as textile raw material. For good fiber yield, a high planting density is desired. The fiber diameter varies, this difference can be credited directly to the cross-section of the cells. When pulled out, their length is in the range of 0.25 meter to 0.75 meters.
There are five visible regions in the cross section of stem of flax plant. The thin layer of wax engulfs the layer of first epidermis, which avoids the moisture loss and shields the plant. Bacteria attacks the stem of flax through this layer during the process of fermentation. The next layer is called as the cortex that have pectic constituents and colouring matter in it. These colouring materials are bleached off at later stages of processing. The next bast layer have fibers in it as bundle form. There are 15~40 bundles in every ring, and each fiber bundle may contain 10~40 cells. The traces of lignin are present in the primary wall and cellulose is present in the secondary wall. The next layers are cambium layer, which separates the fibers of flax from the woody tissues. The last layer comprises of woody tissue. There is hollow space in the centre of the stem.
Figure 9: Cross section of flax plant

(Photo courtesy by National Research Council of Canada)

Figure 10: Microscopic illustration of flax’s plant stem
3.3 Production and Processing of Flax Fiber

3.3.1 Cultivation
Flax plant sown in March or April, it has very short growing period of about 100 days. The plants of flax produce less branches and longer finer fiber. When plants have flowered and seeds are ripened, crop is pulled by root.

3.3.2 Harvesting process
Harvesting can be done both by manual and mechanical methods. Harvesting carried out after 30 days of flax plant blooming/growing, it is being done on a warm, sunny day. The flax plant is not cut but pulled from roots and then dust brushed off from the roots. The flax plants are tied into bundles and stacked in dry and sunny location.

3.3.3 Rippling
Rippling is an important process, which is to remove the seeds and leaves from the stems of flax plant. As previously described that the seeds of flax plant are used as food material and for linseed oil. For extraction of fiber from the flax stem further processing is carried out.
3.3.4 Retting
This is also called as fermentation process and is of vital importance for the extraction of fiber from stem. The details of retting with respect to different types are as follows:

3.3.4.1 Dew retting
The crop of flax after harvesting is spread in the field and left in it for several weeks. The process of retting or fermentation carried due to wetting by dew and rain. It is less expensive and carried in the areas of higher labour cast. Also, the areas with shortage of water use this method of retting. But the fiber from this type of retting are dark-coloured.

3.3.4.2 Dam retting
The flax plants’ stems after harvesting are tied up into bundles and dipped in water dams for about ten days. This type of retting is not commercially followed now a days.

3.3.4.3 Tank retting
After pulling out the stalks of flax plant are separated from seeds by various kinds of metal combs, then tied up in bundles. These bundles are stacked in tanks of water and heated to temperatures of about 30 °C. Tank retting is completed in 3 days. For getting higher qualities of fiber, double retting process is adopted.

3.3.4.4 Chemical retting
Retting process can be carried by using some chemicals like caustic soda, soaps and dilute mineral acids. This type of retting is expensive but it is the fast way of retting [1].

3.3.5 Breaking and scutching
The retted stem is dried completely, the process of drying makes the breaking and scutching. This process makes it easier to remove the woody matter from the fibers. In breaking process, the dried woody matter is crushed off and separated from fibrous material.
3.3.6 Hackling
Hackling is the process of separating the longer fiber of flax from the shorter tow fibers. The fibers are drawn through sets of pins, each successive set being finer than the previous one, this helps in gentle removal of shorter fiber without damaging the longer fibers. It is also known as combing process. Longer fiber of flax are used for the manufacturing of high quality linen products.
3.4 Structure of flax fiber
Length of flax fiber varies from a few inches to one meter. For spinning process fibers may be broken down to smaller lengths suitable for production processes. Flax fiber colour is yellowish white, but its colour varies depending upon the conditions under which it has been retted. The type of retting also effects the colour of flax fiber, as dew retted fiber is usually grey in colour. Flax is generally soft and lustrous in appearance, wax and all other impurities are removed for the improvement of lustre.

Microscopic view of flax fiber is like cylindrical tubes without convolutions. The width of fiber may vary along the length. There are nodes at several points along its length, nodes are just like swellings. The immature fibers are more oval in cross-section but cell walls are thinner and lumen is relatively larger.
Figure 16: Longitudinal view of flax fiber

(Photo courtesy by Centre for Cultural Materials Conservation, The University of Melbourne, Australia)

Figure 17: Cross-sectional view of flax fiber
3.5 **Physical properties of flax fibers**

**Tensile strength**
Flax is usually stronger fiber than cotton, it exhibits the tenacity of about 5.8g/tex.

**Elongation**
The elongation at break of flax fiber is very low, which is 1.8% in dry and 2.2% in wet form. So, it could be termed as inextensible.

**Elasticity**
Flax fiber shows elastic recovery only at lower levels of stretch. It has very high values of rigidity and resist bending. So, it could be said that linen fabrics will have creases but this effect can be minimised by crease-resistant treatments.

**Specific gravity**
Flax fiber has specific gravity of 1.54

**Effect of moisture**
Moisture regain of flax fiber is 12%, it experiences increase in strength when wet.

**Effect of sunlight**
Flax fiber also exhibits loss of strength as exposed to sunlight.

**Effect of heat**
It is resistant to heat at temperatures of 120 ºC and resist its decomposition.
3.6 Chemical properties of flax fiber

Effect of acids
Flax is deteriorated by cold concentrated and hot diluted acid, which degrade the flax fiber. But cold weak acids have no effect on it.

Effect of alkali
It has excellent resistant against alkalis. Due to this reason, linen fabrics could be washed repeatedly with soaps.

Effect of organic solvents
Flax fiber is not effected by dry cleaning solvents.

Effect of insect
Flax fiber has high resistance to insects like moth grubs and insects.

Effect of micro-organism
In dry stat, the linen fabrics has high resistance to micro-organism. But in damp conditions mildew can attack it.

3.7 Applications
Flax fiber has high demand in textile market, and used extensively in different range of product[7]. A few of its applications are as follows:

- Table covers
- Females’ Suiting
- Apparel textiles
- Sewing threads
- Fabrics for decorative purposes
- Bed sheets of linen
- Towels
- Handkerchief linen
- Upholstery
- Decorative wall coverings
- Artist’s canvases
- Panelling
- As insulating materials
- Filtration fabrics
- Automotive textiles
- Composite materials
4. Bast Fibers (Jute)

4.1 Introduction
Bast fibers were known long ago and being used in various areas. They became popular for commercial use about 150 years ago. Now, number of developments was made to make applications of these fibers in technical textiles. Bast fibers are present in the form of bundles existed in fibrous layers, which may serve as a support to strengthen the plant and keep it erect. Bast fibers possess cells having thick walls that overlap over each other and form the continuous strands that are present along the whole length of plant.

Jute is a bast fiber like flax and hemp, and their stems are processed in almost similar manner. Among the other natural fibers, the importance factor and golden-brown colour of jute fiber are the reasons to call it as golden fiber. The global production and consumption of jute fiber make it second to the well-known fiber cotton. It has been categorized as environmental friendly and economically affordable fibre.

The jute fibre has been used by man since prehistoric times and in Biblical times; the jute fiber was used to make sackcloth. It was originated from Mediterranean region and then came to Asia specially India and Bangladesh. Jute has played a role as economically vital crop in Bangladesh and India. Jute lost its past reputation in the economy of Bangladesh and India to some extent, but still having high socio-economic value. Jute being a vital commercial crop of this region played its role in number of different areas. Jute give rise to employment, commerce, and socio-economic value in agricultural and industrial applications. In India and Bangladesh, 76 jute mills are installed having loom installation capacity of 45,012 and 72 mills are installed having loom installation capacity of 26,020 looms respectively. In both Bangladesh and India, about 4 million families nurture jute as a cash corp. India's jute industry offers employment for about 2.5 million people and 1.5 million people has the opportunity of employment in marketing. In Bangladesh's jute industry, about 227,000 labors and 25,000 management people have employment opportunity. Trading companies, management services and industries relating to jute also offers great opportunity for millions of people. For the socio-economic development and welfare of Bangladesh, jute is being used in numerous areas play significant role as a wage earner in foreign exchange. Before the independence of Pakistan, jute was the chief source of Pakistan's foreign exchange. But after the independence of Pakistan and Bangladesh, jute provided that about 84% earnings of Bangladesh's total foreign exchange. But then, there comes an ongoing and clear fall in the earnings. Still jute offers about 30±35% wage earnings for foreign exchange of country [8].

This fiber extracted from the inner bark of the plant of genus “Corchorus” and family “Tiliaceae”, which grows better in humid and hot environmental conditions. Jute belongs to the herbaceous dicotyledons plants having wooden stem. These plants are mostly grown in tropical and subtropical areas. The most favourable environmental conditions for jute cultivation are found in the deltas of rivers of tropics, like the Ganges, the Irrawaddy, the Amazon, and the Yangtze, where extensive flooding made the soil best for its plant cultivation and growth. In Latin America and Africa, jute is preferred over kenaf as it can affect from various environmental conditions and needs long day time for its growth. It has the minimum annual water requirement of 250 mm and temperature between 18° to 33° C wit soil pH of 6.6 to 7.0 [3]. Unlike cotton, the production of jute requires less consumption of fertilizers and pesticides. At earlier, it was spun and weaves mostly in Europe but later Bangladesh and India have emerged as major producers and processors of jute fiber. Chemically jute fiber is composed of two components;
The major amount of non-cellulosic impurity in jute fiber is lignin, which give it some unique characteristics. It is a long fiber of 1 to 4 meters length, lustrous and silky fibre.

The British started the trading of jute fiber since 17th century and it was also used for the British military. The British East India Company and Dundee jute Barons established several jute mills in Bengal. Many Scottish were also immigrated to Bengal to setup jute mills. During World War-I, more than one billion jute sandbags were exported from Bengal. At start, it was processed by hand only until discovered in Dundee that treatment of it with whale oil make it possible to be treated by machine as well.

In 1976-77, production of jute was 3,468,000 tonnes. India accounts for 1,276,000 tonnes, Bangladesh accounts for 851,000 tonnes and Thailand accounts for 183,000 tonnes. Jute was started to spin experimentally in 1820, at Abingdon near Oxford. Dundee mills started spinning jute in 1822 and in 1850, jute industry was developed. Dundee was the main industry of jute manufacturing then India and Bangladesh started to manufacture jute. Jute industry flourished in 18 and 19 centuries.

Jute is a bast fiber belongs to an herbaceous plant that has a height of about 20 feet. Jute fibers are extracted from stalk by retting. It possesses 20% lignin that made it brown in color, and have luster. Cross section of jute consists of 5 to 6 sides. Jute has small sized cells having length of 100 mm.

White jute belongs to “Corchorus Capsularis” and is typically golden yellow in color. This is one of mostly used jute type, to be used in textiles. This fiber has various thicknesses in their cell wall. Fibers are coarser, having diameter of 20 ± 25 µm and length of fibers are just 1± 5 mm. Jute fiber is a strong fiber with very less extension that may results in the stiff, tough and non-elastic fiber. Fibers, which can be spun into yarns, are typically consists of more than ten fibers that overlaps with each other in the bundle. Fibers are joined with each other by a non-cellulosic matter, mostly lignin.

4.2 Development of Fiber

Fibers grow in the phloem tissues, which are present in the stem of the plants. It seems like cells possess wedge shaped bundles which are intermingled with soft tissues and parenchymal cells of the plants. In the rising part of the stem of plant, primary fibers lead towards the development of layer originating from the proto-phloem tissues. Development in the vertical direction comes to an end in the rear parts of stem. Then cambial activity starts in the plant, which gives rise to the formation of secondary fibers.

Mature plants possess a height of 2.5–3.5m and a diameter of about 25 mm. The secondary phloem fiber is about 90% of the total fiber bundles in the stem of the plant. Cell walls of secondary fibers are very thinner, they became thicker and leads to the increment in the weight and strength of the fibers. Fibers developed between the epidermis and the woody part, xylem.
4.3 Fiber Structure
Fiber cells are arranged in rings that collectively forms the cylindrical mesh. Layers are joined together by fibrous bundles, which spread in 3-Dimensional planes through-out the sheath. Single jute fiber comprises of polygonal cells, having lumen core with 10% of cell area in traverse view, shown in the figure. In lengthwise direction, cells are overlapped at “middle lamella” shown in the figure. There exist small hair-like structures with the length of 0.075 cm to 0.5 cm. These structures are called as “ultimate cells”. Bundle of ultimate cells joins in an individual fiber. 8-25 numbers of ultimate cells comprise a bundle and 50 ultimate cells are found to be present in a bundle.

Figure 18: Stem anatomy of jute plant

Figure 19: Cross sectional view of bundle of jute fibers
Comparing jute and flax fibers, flax fibers possess cells that are longer than that of jute. Due to longer cells, surface area increases. Individual fiber strand of flax is much finer than the jute strand. In jute, orientation of crystalline structure is very high, and the very low degree of lateral order i.e. the side by side entanglement of molecules. as compared to flax.

4.4 Chemical Constituents in Jute
The hemicellulose contains polysaccharides having relatively low molecular weight built up from hexoses, pentoses and uronic acid residues. Lignin, a fundamental component is a long-chain material of high molecular weight. The lignin can be wholly removed by chlorination technique in which a soluble chloro-lignin complex is produced and the hemicellulose can be then dissolved out of the residual holo-cellulose by treating it with dilute alkali. The final insoluble remainder left behind is the alpha-cellulose component.

Along with the three fundamental components, jute also contains minor components for example; fats and waxes 0.4±0.8%, inorganic matter 0.6±1.2%, nitrogenous matter 0.8±1.5% and some traces of pigments. These components account to about 2%.

Quantity of contents present in the jute fiber is shown in the table;

<table>
<thead>
<tr>
<th>Contents</th>
<th>Amount %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellulose</td>
<td>60-62 %</td>
</tr>
<tr>
<td>Hemi-Cellulose</td>
<td>22-24 %</td>
</tr>
<tr>
<td>Lignin</td>
<td>12-14 %</td>
</tr>
<tr>
<td>Others</td>
<td>1-2 %</td>
</tr>
</tbody>
</table>

4.5 Cultivation of jute
Jute requires a plain muddy soil and stagnant water. The favorable climate for the cultivation of jute is during the monsoon climate. Temperatures between 20˚C - 40˚C and relative humidity of 70%-80% are favorable for better cultivation. Jute needs 5–8 cm of rainfall weekly, and requires more during the sowing period. Soft water is necessary for the jute production [8].
Table 5: Growth conditions favorable for the cultivation of jute

<table>
<thead>
<tr>
<th>Name</th>
<th>Optimum Temperature (°C)</th>
<th>Minimum Moisture (mm)</th>
<th>Optimum Soil pH</th>
<th>Growing Cycles (days)</th>
<th>Fiber Yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jute</td>
<td>18-33</td>
<td>250</td>
<td>6.6-7.0</td>
<td>120-150</td>
<td>2200</td>
</tr>
</tbody>
</table>

Contents present in the jute fiber greatly affects during the cultivation stages. Their varying percentages at various stages are mentioned in the table;

Table 6: Chemical constituents in jute fiber w.r.t. various portions

<table>
<thead>
<tr>
<th>Component</th>
<th>Pre-bud</th>
<th>Bud-pod</th>
<th>Flower pod</th>
<th>Small</th>
<th>Large</th>
</tr>
</thead>
<tbody>
<tr>
<td>a-cellulose</td>
<td>58.3 %</td>
<td>57.6 %</td>
<td>59.4 %</td>
<td>58.7 %</td>
<td>59.1 %</td>
</tr>
<tr>
<td>Holo-cellulose</td>
<td>86.8 %</td>
<td>87.8 %</td>
<td>87.3 %</td>
<td>87.1 %</td>
<td>86.8 %</td>
</tr>
<tr>
<td>Xylan</td>
<td>15.5 %</td>
<td>14.8 %</td>
<td>14.4 %</td>
<td>13.7 %</td>
<td>13.9 %</td>
</tr>
<tr>
<td>Lignin</td>
<td>12.7 %</td>
<td>12.1 %</td>
<td>12.4 %</td>
<td>12.0 %</td>
<td>12.0 %</td>
</tr>
</tbody>
</table>

4.6 Harvesting of flax fibers
Harvesting the plants at the correct time is most important and requires vast experience. For kenaf, the optimum time for harvesting is when about ten flowers are in bloom, and the older flowers have already set their seed. For jute, the optimum time is judged to be when the plants are in the small-pod stage. Harvesting before flowering generally results in lower yields and weaker fiber, whereas, if the seeds are allowed to mature, the fiber becomes harsh and coarse and difficult to extract from the plant.

The plants are harvested by hand with a sickle and cut close to the ground. The cut stems are then tied into bundles, the leaves removed as much as possible, and the bundles submerged in water for retting. This is the process by which the bundles of cells in the outer layers of the stem are separated from the woody core, and from non-fibrous matter, by the removal of pectin and other gummy substances. The action involves water, microorganisms, and enzymes, and takes between 5 and 30 days for completion, depending on the temperature of the water. Constant supervision is required and the time of removal is critical; if the degree of retting is insufficient, the fiber cannot be easily stripped from the woody core and may be contaminated with cortical cells, whereas, if retting proceeds too far, the fiber cells themselves may be attacked and weakened by microorganisms. Stripping the fiber from the stem is done by hand, after which the fibers are washed and dried.

4.6.1 Fiber Separation
Bast fibers and bark of jute plant need to be separated from the core. This separation has its roots in the ancient history. Separation was done using retting processes; usually biological retting and in some studies, it was reported that chemical retting could also be adapted for the separation of fibers from the core. In India and Bangladesh, retting process is carried out by placing whole jute plant in a pool and allowing the natural decomposition process to decompose
the bark and hence long continuous bast fibers are free. This whole process takes 2-3 weeks with the utilization of large amount of water. Mixture of micro-organisms existing in the water, cause various biological processes other than retting process. Quality of bast fibers will be lower due to the presence of organisms and unclean water.

Major issue regarding retting process is that thicker parts need longer time for retting than thinner parts of the stem. Incorrect retting is that the top parts are fully retted and bottom parts are over-retted. This issue can be avoided by making bundles with upright bottom ends in pool for some days before the whole stem is immersed. In the formation of high quality fibers, correct retting process is very crucial. Factors to improve the fiber quality are good quality water along with the improved micro-organisms. Using clean water and more specific micro-organisms improves the quality of fibers and the effectiveness of retting process.

4.7 Properties of Jute

4.7.1 Physical Properties
Jute is known as Golden fiber owing to its natural golden color and shine. Jute is being a cheaper bast fiber. It is eco-friendly fiber that makes its applications wider. Owing to high content volume of cellulose, it replaces wood. Jute being strong fiber possesses brittle fracture. Jute have little recovery and high initial modulus.

Tensile Strength

Cell wall of jute has irregular thickness that results in the variation of tensile strength between every fiber. Due to those irregularities, it is neither so strong nor durable.

Elasticity

Cells are tightly packed with each other that gives it little or no elasticity.

Elongation

Jute being a stiff fiber does not appreciably stretch. Elongation at break of jute is 1.7%.

Specific Gravity

Jute has specific gravity of 1.5%.

Fineness

Jute being a coarser fiber has a diameter of 6 to 20 micrometers.

Aging

Presence of moisture leads to the degradation resulting in significant loss of strength. In the dry environment, it remains unaffected, but non-cellulosic contents make it chemical sensitive.

Attack of micro-organisms

Jute has higher resistance to rot than other natural fibers, due to lignin,
Table 7: Properties of jute comparing with other fibers

<table>
<thead>
<tr>
<th>Fiber</th>
<th>Density</th>
<th>Young's Modulus (GPa)</th>
<th>Tensile Strength (MPa)</th>
<th>Elongation at break (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jute</td>
<td>1.44</td>
<td>10-30</td>
<td>393-773</td>
<td>1.5-1.8</td>
</tr>
<tr>
<td>Flax</td>
<td>1.54</td>
<td>27.5-85</td>
<td>345-2000</td>
<td>1-4</td>
</tr>
<tr>
<td>Ramie</td>
<td>1.5-1.56</td>
<td>27-128</td>
<td>400-1000</td>
<td>1.2-3.8</td>
</tr>
<tr>
<td>Hemp</td>
<td>1.47</td>
<td>17-70</td>
<td>368-800</td>
<td>1.6</td>
</tr>
<tr>
<td>Sisal</td>
<td>1.45-1.5</td>
<td>9-22</td>
<td>350-700</td>
<td>2-7</td>
</tr>
<tr>
<td>Coconut</td>
<td>1.15</td>
<td>4-6</td>
<td>131-175</td>
<td>15-40</td>
</tr>
<tr>
<td>Cotton</td>
<td>1.5-1.6</td>
<td>5.5-12.6</td>
<td>287-597</td>
<td>7-8</td>
</tr>
<tr>
<td>Nettle</td>
<td>1.51</td>
<td>24.5-87</td>
<td>560-1600</td>
<td>2.1-2.5</td>
</tr>
<tr>
<td>Kenaf</td>
<td>1.2</td>
<td>14-53</td>
<td>240-930</td>
<td>1.6</td>
</tr>
<tr>
<td>Bamboo</td>
<td>0.6-1.1</td>
<td>11-17</td>
<td>140-230</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Properties</th>
<th>White Jute</th>
<th>Tossa Jute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell Unit Length</td>
<td>0.8-6.0</td>
<td>0.8-6.0</td>
</tr>
<tr>
<td>Length/breath ratio</td>
<td>110</td>
<td>110</td>
</tr>
<tr>
<td>Hermann’s angle of orientation</td>
<td>7°-10°</td>
<td>7°-9°</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>1.4-1.45</td>
<td>2.00-5.00</td>
</tr>
<tr>
<td>Moisture regain</td>
<td>12.5</td>
<td>12.5</td>
</tr>
<tr>
<td>Swelling % in water</td>
<td>20.0-22.0</td>
<td>20.0-22.0</td>
</tr>
<tr>
<td>Tenacity</td>
<td>27-36</td>
<td>16-35</td>
</tr>
</tbody>
</table>

4.7.2 Chemical properties

Moisture

Jute has the ability to absorb moisture up to 23% and retains 13.75%.

Effect of Acids

Acids have adverse effect on jute fibers.

Effect of Alkali

There is no adverse of alkali on jute fiber.

4.8 Applications

Jute is widely being used since long time ago. It is mostly used in sacks, bags and other various types of packing articles. Jute is also being used in carpets, door and table mats, rugs, and finer jute is used in home furnishings and drapes, handbags, hats, shoes and their linings, wrappings for various purposes, ropes and strings, upholstery and wall covers. Jute is now replacing wood and used in composites [9]. Jute as a composite is also used in the manufacturing of building materials, like ply boards as a replacement of wood, doors, and their frames. Fishing boats is now manufactured by jute composite due to having its high impact resistance, anti-corrosive nature, and strength. Later, jute fabrics are used as carpet backing, and it accounts for about 15% of the world’s fiber consumption [10].
5. Leaf Fibers

5.1 Introduction
Leaf fibers are extracted from the leaves of monocotyledonous plants, sisal is a leaf fiber comes from the plant Agave sisalana. These plants are indigenous to Western hemisphere, especially Mexico and Central America. Now a day the leading producers of it are countries like Kenya, Mexico, Haiti, East Africa, Tanzania and Brazil. Sisal fiber obtained its name from Yucatan port of Sisal. From this port on the Gulf of Mexico, the sisal fiber were exported. Leaf fibers are generally categorized as coarse and hard fibers as compared to bast fibers, but some leaf fibers are softer than some bast fibres. Due to this fact, sisal fibers are mostly used for the manufacturing of ropes and cordage, and to produce some textile fabrics.

Sisal fiber is the hardest fibers among all the vegetable fibers. The plant of Agave from which the sisal fibers are extracted has various varieties according to the different areas of production. Commercially two varieties are mostly used named as Agave Sisalana and Agave Fourcroydes. In East Africa, the production of sisal fiber flourished gradually and Tanzania produced 30,000 tons of sisal fibers by 1960. The other sisal producing countries flourished their business, and in 2008 Tanzania, Madagascar and Kenya respectively produced 23,000, 8,000-10,000 and 3,000 tons of sisal. Some smaller quantities were also produced by Venezuela, Cuba and Mozambique [11].

5.2 Structure of Sisal fiber
The strand of sisal fiber has a length ranging from 2 to 4 feet, strand comprised of several fibers held together by natural gummy substances. As shown in the fig. 1, the leaf of sisal fiber can further be divided into three zones like ground, median, and peripheral. The ground zone contains mechanical and ribbon fibers. The median zone contains coarser ribbon fibers having crescent like cross section. The peripheral zone comprised of mechanical fiber having round like cross section. The maturity of fibers at the cutting time determine the strength, length and thickness of fibers. The fibers from immature leaves are generally weaker, shorter and finer. The maturity of sisal leaf is indirectly proportional to its distance from the ground. The normal fiber cells of sisal fiber are stiff and straight. The lumen varies in definition and thickness, the thickness of lumen is indirectly proportional to the thickness of cell wall. Some of the cells cushion and rectangular shaped. Sisal also contains about 6% of lignin based on dry material.

Figure 21: Cross-sectional view of Sisal fiber

5.3 Production and processing of sisal fiber
The normal plants of sisal produce 4.5-7 kg of sisal fiber throughout its lifetime. The leaves are cut from the plant, the lower 2-3 rows of leaves from plant are cut manually from each plant. The leaves are cut one by one and bundled together in a group of 20-50 leaves tied together. The
time between cuttings of leaves and extraction of fibers from them is of vital importance, as if leaves got dry then extraction of leaves become difficult. The extraction difficulties of dry leaves are mainly due to hardening of gummy substances. The process of extracting the fibers from sisal leaves is commonly known as decortication. In decortication, the outer layer of leaves is removed by peeling it off and the fibers are recovered. The other ways to recover the fibers from sisal are hand scraping, retting and raspador machines. Dual retting of sisal leaves is also used for convenient extraction of fibers. The double retting process is carried by removing the half-retted leaves from the tank and second retting is performed after few months. Some large decortication machines can process 200-300 leaves/min. In these machines, leaves are first crushed by grooved metal rollers, then gripped from the centre of the leaf by the help of pair of chains and exposed to scraping action of a bladed drum. After that second pair chain grip the leaf from some other point to expose the unscraped portion to the drum. For the separation of plant material from the fibers, water is sprayed during decortication process. The useable sisal fiber tow is then recovered from the waste water. In next stage, the fibers are dried in sunshine or by using spin dry centrifuges. After drying the fibers are brushed to remove the dust or any other foreign matters from the fibers.

5.4 Properties of sisal fibers
The lumen of sisal fiber contains calcium oxalate crystal and is 18-25 mm. Some of the important properties of sisal fiber are shown below.

<table>
<thead>
<tr>
<th>Various properties of sisal fiber</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/cc)</td>
<td>1.20-1.45</td>
</tr>
<tr>
<td>Porosity (%)</td>
<td>17.0</td>
</tr>
<tr>
<td>Moisture regain (%)</td>
<td>11.0</td>
</tr>
<tr>
<td>Specific heat (cal/g^oC)</td>
<td>0.317</td>
</tr>
<tr>
<td>Fineness (d-tex)</td>
<td>10.0</td>
</tr>
<tr>
<td>Tenacity (g/den)</td>
<td>6.71</td>
</tr>
<tr>
<td>Initial modulus (g=d-tex)</td>
<td>257</td>
</tr>
<tr>
<td>Modulus of elasticity (N/tex)</td>
<td>25-26</td>
</tr>
<tr>
<td>Extension at break (%)</td>
<td>1.9-4.5</td>
</tr>
<tr>
<td>Work of rupture</td>
<td>0.044</td>
</tr>
<tr>
<td>Breaking length (km)</td>
<td>36-45</td>
</tr>
<tr>
<td>Tensile strength (Mpa)</td>
<td>507-855</td>
</tr>
</tbody>
</table>

5.5 Applications
Sisal fiber has several applications. As sisal has higher percentage of cellulose, so its pulp used as a substitute for wood fibers. High quality papers and cardboards with high endurance properties are also made from sisal. Traditionally yarn, rope, twine are the products made from sisal. It also has high value applications in plastic and reinforced composites due to low density of sisal. Sisal composites are being used in furniture and other automotive components. Sisal can replace asbestos in brake-pads and roofing. One of the major use of sisal is in buffing cloth, because its strength is enough for polishing and softness enough not to scratch the surface of metal being buffed. Sisal fiber board can be used as a substitute of wood to provide the insulation properties.

The by-products produced during sisal fiber extraction can be used in the manufacturing of building material, pharmaceutical, and biogas. In Tanzania, the sisal industry and UNIDO funded the plant used to produce electricity, biogas and fertilizers.
6. Mineral Fiber

6.1 Introduction
Asbestos is a naturally occurring fiber present in rocks, its fibers are closely packed to each other and gives grainy structure to the rock. Its prime characteristics making it distinguished from the other natural fibers that it is highly heat resistance and non-inflammable. Chinese used asbestos in making false sleeves, which were put into fire for cleaning purposes. By burning process, all the dust burnt off leaving asbestos sleeves clean. In 1710 to 1720, a factory was established in Russia for the manufacturing of asbestos textiles, gloves and socks. But today the use of asbestos is strictly restricted and prohibited due to its hazardous impacts on human health.

6.2 Production and processing of asbestos fiber
Asbestos is found in naturally occurring minerals which are in the form of fibrous crystalline. The followings are the three significant minerals which have asbestos,

- Amphibole
- Anthophyllite
- Serpentine

Amphibole have several varieties like Actinolite, Tremolite, Mountain leather, Crocidolite, and Amphibole asbestos. Among these all, Crocidolite or blue asbestos is an iron sodium silicate, which occurs as long flexible bluish fibers having silky lustre. Crocidolite has higher strength among all asbestos fibers but with lower heat resistance. Mountain leather occurs in the form of leathery sheets or matted fibers. Anthophyllite is magnesium iron silicate which is found in the form fibers or thin plates, it was not used as source of asbestos. Serpentine is hydrated silicate of magnesium which is found in the form of fibers. It has two varieties, Chrysotile and Picrolite. Chrysotile occurs as narrow veins in the serpentine rock in green to brown colour. It is of great importance as it provided the major source of asbestos fiber. There three main operations performed in the processing asbestos,

- Opening
- Carding
- Spinning

At first stage of opening raw asbestos is given with an initial crushing. During crushing great care being taken to avoid any damage to the brittle fibers. For further opening toothed rollers are deployed, powdered rocks and dirt are eliminated with the help of grid bars. For the removal of short fibers and impurities, asbestos is processed through carding operation. Longer fiber are delivered in the form of loose web, which is then converted into roving. The formed roving is used to make yarn by using conventional spinning methods. Generally doubling is used to avoid the variations in the yarn.
6.3 Properties of Asbestos fiber
The significant property of asbestos fiber is its resistance to fire and heat. It can withstand higher temperatures and be used as fire resistant fiber. Asbestos fibers are not attacked by insects and micro-organisms. It is also highly resistant to acids, alkales and other chemicals. The main features of the asbestos fibers are as follows,

- Heat resistance
- Good insulation
- Chemical resistance
- Good strength
- Flexibility
- Electrical resistance

Most forms of asbestos are chemically inert and heat resistant, its odourless fibers neither evaporate nor dissolved in water and organic solvents. But serpentine chrysotile is soluble in the acid. It has many applications due to its thermal stability, non-flammability, electrical and thermal resistance. Its colour varies from type to type and metallic composition. Crocidolite having sodium and iron as its metallic elements, is the most colourful form of asbestos with a wide range of colours including blue, green and lavender.

6.4 Applications
Asbestos fiber was used in the manufacturing of twines, gaskets, cloth and brake linings. Its major application areas were those in which heat and fire resistance was required. The areas include industrial packing, conveyers for high temperature materials, fire-resistant suits, and electrical windings. The inertness of the asbestos fiber made it very much suitable for industrial usage[12]. Asbestos binds with better insulating materials to form better construction materials. But as mentioned earlier, currently asbestos fiber is not used due its hazardous impacts on human health.
References


7. Animal Hair

7.1 Introduction
Animal fibers are one form of natural fibers. These fibers particularly consist of large proteins. These consists of silk, hair/fur (wool) and feathers as well. The animal fibers are largely used by hand spinners as well as manufacturers. All the animal fibers do not have same properties. There are wide variations among distinct species as well as within the species. They differ under microscopic studies from each other. These variations start from diameter of fiber to microstructure of the fibers. The nutritional and metabolic state of the animals cause these characteristic variations. The length of fibers in this category depends upon the active growth phase of follicle. Pigmentation, transverse shape and general contours of the surface are other characteristics of hair fibers that varies widely.

Wool fiber is one of the animal fibers. This fiber is naturally high crimped and protein based. The structural parameters along with the fineness of these fibers is depended on the source it was obtained. They have distinct properties varying from specie to specie ranging from soft, fine to a coarser wool. Generally, the natural fibers including animal fibers are different individually from each other while the synthetic fibers look alike. Mammalian fibers including wool fibers consist of various parts which are categorized as cells, cuticle cells and cortical cells. Merino sheep that produce excellently fine quality wool consist of cuticle that constitutes almost 10% by weight of the overall fiber weight. The cuticle of these wool fibers consists of one cell thickness.

Human hair fibers are also an example of mammalian fibers. In contrast to wool fibers these fibers do not have their usage in textile fields due to certain technical limitations. Human hair by contrast may consist of ten layer of cells of the cuticle, and about thirty-five layers of pig bristle cuticle. There are different sections of cuticle cells. These sections consist of exocuticle cells and the endocuticle cells. The exocuticle cells contain higher Sulphur content while endocuticle cells contain lower Sulphur contents. Epicuticle is a membranelike proteinaceous band. This band forms the outer exposed surfaces of the cuticle cells. Additionally, there is a resistant barrier composed of lipid component. These are the moieties which play as a functional component of fiber surface and significantly important in fiber protection [1].

7.2 Classification of the wool fiber
There are various factors that affect the quality of wool fibers such as the breeding circumstances, weather and climate, food and care etc. For instance, natural grease is dried by excessive moist likewise, harder and heavier fibers are produced by cold weather conditions. The wool fiber is classified in two following ways,

7.2.1 Classification of wool by Sheep
The wool fiber is categorized on the base of sheep from which it is obtained as mentioned in following.
Merino Wool

The best quality wool is considered of Merino sheep, these sheep are grown in Spain. The characteristics of these fibers are as follows,

These wool fibers are more elastic, strong and of fine texture. The range of these fibers is between 1 to 5 inches (25 -125mm). Amongst the various types of wool fibers, merino wool fiber has more quantity of crimp and highest number of scales. These two elements add to its quality of superior warmness and spinning. This wool type is used for the best kind of wool productions and clothing.

Category – Two Wool

England, Scotland, Ireland and Wales are originating areas of this category of sheep. The key attributes of these wool fibers are as follows,

The wool fibers are relatively firm, fine, strong and elastic as well. The length range of these fibers is between 2 to 8 inches (50-200mm). The have a great number of scales/inch and have good quality of crimp.

Category – Three Wool

United Kingdom is the originating area of this type of sheep. The properties of wool fibers sheared from such type of sheep are as follows,

The texture of such fiber is harsher as compare to first two categories. These fibers have less scales and crimp comparatively to previous classes and length range of these fibers is between 4 to 8 inches. These fibers are smoother in texture and shinier. These fibers are less elastic and less bouncy than other previous types. They are used for good quality of cloth manufacturing.

Category– Four Wool

This category belongs to mongrel sheep. This type is also called half-breeds. The qualities of fibers obtained from such sheep are as follows,

The range of length of such wool fibers are between 1 to 16 inches (25-400mm). The texture of such fibers is harsh, coarse and like hair and have few scales and less crimp. These wool fibers are smoother and brighter. Due to its qualities of less elasticity and less strength, the demand of such wool fiber type is not desirable. This type is mostly used for carpets, rugs and cheap clothing of low grade[1], [2].
7.2.2 Classification by Fleece:

The procedure through which woollen fleece is removed from a sheep is called “Shearing”. The spring season is considered best usually to shear fleece from sheep but the time of shearing is different in various regions of the world. Before shearing, sheep are not washed. Sometimes, sheep are dipped into an antiseptic bath according to law. The classification of wool fibers by fleece is as follows,

Lamb’s Wool

When the fleece is removed for very first time from the lamb, which is of 6 to 8 months old is called lamb’s wool. This type is also called as fleece wool or first clip. It gives a softer and smooth feeling because fleece is not cut off and it has natural tapering ends.

Hogget Wool

When the fleece is obtained from the sheep of 12 to 14 months old, which is not obtained before, it is called Hogget wool. The fiber such wool is fine in texture, smooth bright and matured. It also has tapering ends like lamb’s wool. This wool is mostly used in warp yarns.

Wether Wool

This type is obtained from the sheep which is of more than 14 months. This sheep is not shorn for first time. In actual, these fleeces are shorn after the first shearing. This fleece type has more soil and dirt in it.

Pulled Wool

The wool which is obtained from such animals which are slaughtered for meat is called pulled wool. The wool is obtained from the fur or pelt of the slaughtered animals by using different chemicals. This fleece is considered of low quality and is used for cheap and low grade clothing.

Dead Wool

The wool which is shorn from the dead sheep whether is died accidently or by age. This type is different from pulled wool so should not be confused with it. This fleece is definitely inferior in quality and also uses in low grade clothing.

Cotty Wool

This type of fleece is shorn from such sheep which have exposed to severe weather conditions. As it is mentioned earlier, the severe weather and climate conditions affect badly the quality of wool obtained. The texture of such wool type is harsh and has brittles. This is considered of low and poor grade quality.

Tag locks

The fleece which is torn, damaged, discoloured or ragged is known as tag locks. This wool type is sold a part from others due to lowest quality of wool.

7.3 Growth and structure of wool fibers

The structure of wool fiber can be investigated in two ways:

I. Macro-structure of wool
II. Micro-structure of wool
7.3.1 Macro-structure of wool
The wool fiber has certain properties like fizziness, thin to thick and regular fleece. The harsh wool fleece has 4 crimps/10 centimeters while fine and smooth wool has 10 crimps/centimeter. With increase in the diameter of wool fleece, the total amount of crimps per unit length declines. Crimps per unit length determine quality of wool fibre, whether it is fine or coarse. The crimped shape of wool fibers keep fibers from positioning themselves too near when reeled into yarn. The air spaces in the material are the main reason of the warmness of the fool fibers not the fibers.

The length range of the fine fiber is start from 5cm to 35 cm for harsh fiber. Diameter range for fine and smooth fiber is 14μm and for coarse fiber is 45μm. For fine fiber and smaller, the ratio of Length width ranges from 2500:1 similarly for Harsh and lengthy fiber the ratio is 7500:1. The colours of fiber also differ from white to off white colour.

Di-sulfide bindings which functions like chromosomes are the reason of the colour variations of the wool. When the colour of fiber is from cream to dark off white colour, the reason behind this is the more polymer degradation on the outer layer of the fiber because polymers of wool is very responsive to weather conditions, climate and air pollutions[3].

7.3.2 Micro-structure of wool
In microscope, length wise the structure of wool is like cells are overlapping on surface. These overlapped cells on the surface are called epithelial and usually it’s also called scales which indicate the top or outer layer of the fiber. The cross-sectional view of wool fiber is of oval shape. When the wool fiber is permanently shrinked in length, width and thickness, this procedure is called Felting. Sue to notched outer layer of the fibers felting of the wool is possible. This outer layer consist of epithelial or scales. This notched structure of the wool fiber results lesser rubbing. If the wool fiber go to root ward way, the process of felting can be raised with the help of heat, some chemicals like acids or alkali.

![Figure 22: Raw wool which is amplified 25000 times and overlapped scales toward the tip of the wool fiber](image)

There are three main parts of wool fiber when observed under microscope. These components called the cuticle, cortex and medulla.

Cuticle
The overlapping epithelial cells or scales around the outer layer of the wool fiber are called cuticles. Three cuticles are as follows,
The most outer layer of the wool fiber is known as epi-cuticle. The scales on the fibers make the exocuticle. The third cuticle is endocuticle which can be defined as a connecting layer binding the scales on the outer surface of the wool fiber.

Cortex

This part is also called Core, this component make 90% of the volume of the wool fiber. It contains numberless lengthy cells of spindle shape or in other words cortical cells. Ortho and Para cortex are two regions of composition of cortex. More dye is absorbed by the ortho than para cortex. These both components have spiral like binding around each other. Around the diameter of the cross sections of wool fibers, fine wool have 20 cells of this type while harsh wool fibers consist 50 cortical cells.

Medulla

In harsh and non-fine fibers, there is an empty space extending lengthwise to centre of the fibers. This space is called medulla.

7.4 Properties of wool fibers

Wool fibers are extremely complex and possess different properties. These properties are subdivided into three groups which are given below.

7.4.1 Structural Properties

Wool fibers have specific structure which vary from specie to specie. This structure cause variation of properties of these fibers from each other. These fibers are highly cross linked keratin proteins. There are 17 different amino acids which are combined in different ratios to form these keratin proteins. The ration of these amino acid in wool is dependent upon the source of the wool. The following table consist of the average contents of these amino acids for major verities of wool fibers.

The protein chains present in wool are joined periodically via a disulphide cross-linked cystine, which is a diamino acid. The two adjacent chains have this diamino acid. These protein chains spiral themselves on each other. The amount of these self-spirals is around 40% of the total chains. Hydrogen bonding hold these chains internally. The helical structure of these protein fibers is less regular and shows less close packing at the places where crosslinking or bulky amino acid groups are present. The fibrils are formed from these packed protein structures. These fibrils are the building blocks for cortical cells which are spindle shaped and make the internal structure of the fibers. This internal structure of fiber is called cortex. This cortex is covered by a cuticle cell wall which is scale like layer. This layer is responsible for the scale like appearance of these fibers running along the length of the fiber[4].
7.4.2 Physical Properties
The physical properties of wool fibers vary in dry and wet state. The strength of wool fibers range from low to moderate. The tenacity of wool fiber is 9 – 18 g / tex in dry state while 7 – 16 g / tex in wet state. The wool fibers possess high elongation at break which also vary in dry and wet state. It is 25% to 40% in dry state and 25% to 60% in wet state. At lower elongations wool has excellent recovery to the original state. 99% recovery of wool fibers were noted at an elongation of 1%. While this recovery percentage falls to 65% when this elongation reaches to 20%. Excellent resilience and readily recovery behaviour is shown by the wool fibers except for high humid conditions. Like structural parameters the physical properties of the wool fibers also greatly dependent on the sources it is obtained. The stiffness as well as the diameter of individual fibers vary much as the source changes. Wool fibers have high moisture regain which vary from 13% to 18% under standard conditions. The moisture regain of wool fibers reaches to an even higher level of 40% when the humidity of the environment approaches to 100%. The specific gravity of these fibers ranges from 1.28 – 1.32. Only the solvents those can break the disulphide cross linkage of wool fibers can dissolve it otherwise it will remain insoluble. However, it tends to swell in polar solvents. Wool fibers are very little affected by the higher temperature even at 150 degree centigrade and it has low heat conductivity which makes it good heat insulator. The bulky structure of these fibers also play its part in insulation properties of these fibers. Therefore, textile structures of wool fibers entrap air molecule in it. No significant static charge is built up on wool fibers at moderate relative humidity.

7.4.3 Chemical Properties
There are some chemical properties related to wool which need to be known. Among these properties, the behaviour with acid and base is most important. Wool fibers are resistant to the acid attacks. But wool is highly vulnerable to the bases. Even weak bases can attack the wool
fibers at lower dilutions. The nest is the reaction with oxidizing agents. These agents can damage the wool fibers and colour them. This damage and colour change will be irreversible. The example of such oxidizing agent is oxidizing bleach e.g. hypochlorite. The reductive scission is done of the disulphide bonds of wool fibers by the reducing agent, because of this scission the wool fibers eventually dissolve. The wool can be reduced and pleats can be flat set or permanently set by using the use of reducing agent under controlled conditions. Wool fibers are susceptible to be attacked by several species of moths which can digest and dissolve the wool fibers. Wool fibers show resistance to other biological agents like mildew. Slow degradation and yellowing of wool fibers was observed under the influence of ultra violet light ranging from 300 – 350 nm. Wool fibers also degrade and become yellow on heating above 150 degree centigrade and these fibers transform to char at a temperature of 300 degree centigrade.

7.5 Applications
Wools fibers have lustre from higher to moderate level and the fabrics made from these wool fibers after subsequent processes have soft to moderate feel or hand along with the good drapability. The wool fibers are excellent moisture absorbers and have very good moisture transmission properties.

The wool fibers have good stretch and recovery properties which compensate its lower to moderate strength. This low strength prevents pilling to be appeared on the surface of these fibers. Also, these fibers have fair abrasion resistance. Hot and moist conditions can cause wrinkles in wool fibers. Without these conditions, wool fibers resists wrinkling effect. Reducing agents are required to retain creases in these fibers otherwise crease retention is very poor.

Wool fibers dyes easily and these fibers show good colour fastness. Wool fibers cannot be laundered due to the felting action with hot water along with the agitation. So, these fibers are dry cleaned. Warm water can also be used to wash them with a mild detergent without any agitation. Wool fibers show affinity towards water molecules, this affinity cause wool fibers dry slowly. These fibers can be ironed at higher temperatures even at 150 degree centigrade or below without steaming. The LOI value of wool fibers is 25 which makes them self-extinguishing fibers. Even in contact with the flame these fibers burns slowly.

Wool fibers have extensive applications in textile field where ever comfort is required jointly with aesthetics. In apparel, it is being used for men as well as women dresses including outer wear and specifically for winter clothing. Felts, suits, blankets and carpeting are the other applications of wool. The wool fibers are sometimes used in blends with natural cellulosic fibers and with man-made fibers.
8. **Silk fiber**

8.1 **Introduction**
Silk is a natural protein fiber. The structures formed are cocoons or webs, fundamentally this fiber is pure protein, in some arrangements it has lowest quantities of sugars and minerals. It is from animal origin. It is known as Queen of Fibers. Instead of cultivation it is produced by the insects like silkworms and caterpillars in the form of continuous fine strands of fibers. It is the only natural fiber that is filament fiber. Following back the Chinese history the silk culture started around somewhere 2640 B.C. It started when Si-Ling-Chi, the queen found out the way to rear the caterpillars and started extracting the silk fiber from the cocoons made by caterpillars. They named it “Sericulture”, meaning the manufacture of silk. From china this technique reached Japan and then Korea. For more than 5000 years silk textile industry is familiar to silk fiber, its inimitable lustre along with tactile properties and dyeing properties makes it exceptionally good fiber [5]-[7].

Silk fiber exhibit remarkable behaviour towards thermal waves and electromagnetic waves. On commercial scale hot water having soap in it is used to eliminate protein in form of glue from cocoons and the lasting fibroin silk is wound on reels. A cocoon produces almost 300-1200m of silk. There are many types of moth near about 300 to 400 but only few of them are profitable to collect. Because the silk collected from these few moth caterpillars has good molecular level. It is fine, horny, shiny and yellowish in colour.

Silk is a fiber made with vast verities of proteins like keratin, elastin, collagen and some other type [8]. Such proteins reflect nature’s corresponding man-made block copolymers. Apart utilizing them directly in formation of different materials, experimentally reachable archetypal structures having easier and precise genomic template-based protein synthesis can be achieved using these fibrous proteins. Silk fibers have even surface and are radiant as they have irregular diameter. If viewed through their cross section these fibers have trilateral shape but with curvy edges.

8.2 **Silk in different forms**
Bombyx mori (silkworm cocoonsilk) is the most categorized and well known of all the types of silk, as sericulture has heightened this material in excess of thousands of centuries in China [9]. The ease with the production of silk worms is that they can be upraised in massive quantities, which allows sound levels for commercial production. The process can be as flexible as it could be carried out at local and small scale without heavy industry. The rural environment having naturally available nutrition sources for silk worm like Mulberry leaves is very preferable.

Tussah silk is formed by mixture of several species of silkworm, specifically mylitta, native to India and pernyi, a Chinese native. These worms have specific feed that is oak Quercus serrate. Another type is dragline silk, formed by spiders that have the ability to form orbs. It is opposite in case of production than cocoon silk, as spiders were found to be very problematic to cultivate in massive quantities because of introverted and voracious nature. There could arise another problem like in form of spider’s webs there is a fair chance for silk proteins to get strangle in each other and damaged and tainted silk fibres.

Apart from silk worms and spiders there are other species that forms silk fiber, like mites and some kinds of scorpions. Earlier silk made by these species was not considered or as a matter of fact was not known by the world, but in recent years this trend is changing and these types their structure and properties are now also well-known globally.
8.3 Extraction of Silk from Silkworm Cocoon
Silkworm B. mori formulates the silk with the help of two basic filaments of fiber covered with a material named sericin protein, it gives a sole thread of diameter 10-25mm, that thread consist of two different fibers in its core having 5-10mm diameter. Discussed earlier the feed of silk worms is mulberry leaves and rearing of silkworms start with the birth of leaves. After the mouth lay eggs, the process of hatching starts [10]. This fulfill the 90 % demand of silk in the world. As it is a common type of silk, it is easy to acquire it. It is produced abundantly in the countries li China, Japan and Korea.

8.3.1 The process of Hatching
In silk farms artificial warmth is provided, and in little days caterpillars starts to appear having as small size as 3mm. This process is carried out by scattering the eggs in the large trays in hatching farms. A perforated paper is used to provide chopped mulberry leaves to the worms, and then the worms climb over the perforation of paper. 1oz of eggs has capability of producing almost 36,000 silkworms.

8.3.2 The process of Moulting
This process consists of eating of silk worms and sleeping that last for four periods lasting a day. At the time of sleeping the worms develop new skin and shed old one. When fourth moulting is finished, the worms eat twenty times of its own weight, it is the period of final feed and it continues for almost 10 days. After 35 days of hatching its weight increases ten thousand times of its birth weight [11] [12]. Its weight reaches about 7 g and size cross 76mm and now it is converted into a caterpillar of greenish-white colour and it has silk in liquid form in it and ready for spinning. The next step of worm is the formation of cocoon.

8.3.3 Formation of cocoon
Silkworms have two glands that hold liquid silk, and come out through” spinneret”, an evacuation duct found in its head. As soon as liquid silk leaves the duct in form of filaments coated with sericin, it starts to harden. In the whole process the worm moves back and forth its head and hence formation of cocoon occurs. The strand used for this purpose can be up to 1 mile or 1.6 km in length. The process of spinning lasts for 2 to 3 days. After the completion of cocoon the worm starts to transform in to pupa that leads its transformation into a moth and moth can damage the filament of silk by the secretions it exert to make a hole and leave the cocoon. So on silk farms it should be killed before it turns into pupa or mouth.

Tussah Silk
It is produced by Tussah Silk Worms. This type of silk has light golden to dark brown colour. This different colour is due to tannin-rich leaves eaten by Tussah Worms. This silk has great strength.

Spider silk
Spider silk is being produced by spiders. This type of silk is most difficult to produce because we cannot breed spiders like other silk worms. Also, they cannot produce as much as silk the silkworms can produce [13]. It can be obtained by spiders and these filaments are so fine that they are difficult to see with naked eye. Golden garden spider can spin a filament of diameter 0.00025mm. Silk is formulated in the form of orb webs through the secretions found in abdominal glands [14]-[16]. With the variation in the specie of spiders the quality and characteristics varies. Silk from spiders and from silk worms both show edifying divergence. Some mechanical parameters can be seen in the table given below.

8.4 Structure of Silk Fiber
Silk is lustrous and soft feel fiber. Cross section of silk is roughly elliptical. Figure shows that twin triangular fibroin filaments, which are covered by sericin, face towards each other. The triangular cross section of the silk filament makes it beautiful, soft and lustrous. After degumming process, twin fibroin filaments can be separated into individual filaments giving more fineness and more lustre to fiber. It lacks longitudinal features along the longitudinal-section.
8.4.1 Crystalline structure in polymers

Most of the cocoon silk and dragline silk fibers have accumulated b-pleated sheet structures that are antiparallel to each other and crystalline in nature [17]-[19]. Silks are taken as semi crystalline fibers, having a crystallinity of 30 to 50% in the spider silk, 62 to 65% crystallinity in the silk of cocoon originated from B. mori silkworm, and about 50–63% in wild silkworm cocoons. The axis of polymer’s chain is analogous to axis of fiber in the case of the b-sheet crystals. The degrees, up to which these constructions form, including their alignment and magnitude, have a direct impact on the mechanical properties of silk. The repetition of the glycine-alanine structure is one major factor which caused the development of b-sheet. A – Helical structures can be formed by some other types of silk like ants, bees and wasps or structures from insects. The cross b-sheets are categorized by the chain axis of polymer that is perpendicular to the axis of fiber. 1950’s the first structure of silk that was considered as crystalline structure was antiparallel and hydrogen bonded beta sheet that was based on the categorization of B. mori fibers.

There are three crystalline types of silk that have been reported as silk one (pre-spun), silk two (spun), and the last silk three (interfacial). The cell dimensions are consistent in these structures which have a crystalline form of structure, in its chains of protein have a antiparallel relation with the chain of hydrogen bonds that are perpendicular to the axis of chain between the amine groups and carbonyl groups, Van der Wall forces hold the interactions between the sheets [20] [21]. The glycine – alanine crystalline structure form beta sheet that repeats itself in asymmetry in silk worm fiber, in which one surface project alanyl methyl groups to the second surface of the same sheet.

8.5 Physical parameters

Silk has proven itself a strong fiber but with a moderate amount of retrieval from distortion. In dry form, it has tenacity 3-6 g/d (27-54 g/tex) and in moist form 2.5-5 g/d (23-45 g/tex). Experiments have shown that it has 90% elastic recovery from 2% elongation and after 20% elongation its shows 30%-35% recovery. Stiffness is moderate in silk fibers and good recovery from deformation but it depends upon temperature and humidity conditions. It exhibits specific gravity of 1.25-1.30 and moisture regain of 11% under standard conditions. There is no comparison of spider silk when there comes energy absorption before breakage. The size of crystalline areas and their orientations have a strong impact on physical properties of silk fiber. Silk has bad elastic recovery because it’s a crystalline polymer it does not allow polymer motion which could only occur in amorphous region.

They show very remarkable behaviour in form of resistance when axial compression is applied, the study was conducted on knotted single fibers and on the microscopic assessment at site knot curve no kink-band failure was found. Silk will resist higher temperature of 140 degree centigrade. It decomposes at 165 degree centigrade. As silk is a protein fiber so Cloth Moths and Carpet...
Beetles can harm the silk while Mildew and Bacteria does not harm it unless it is kept in extreme conditions. It is decomposed by strong acids but dilute acids do not harm the silk fiber while weak Alkalis like soap cause little damage to silk.

8.5.1 Thermal and Chemical configuration
When thermally examined cocoon silk from B. mori shows $T_g$ of 1758 °C. while dragline silk also shows thermal stability at 2308 °C, analysed through TGA (thermal gravimetric analysis). With the help of dynamic mechanical analysis (DMA), thermal transitions between the fibers were observed, first at 758°C that occurs in the amorphous region and the other at 2108°C which indicates glass transition temperature or partial melt temperature.

Fibroin heavy chain of about 375,000Da molar weight and fibroin light-chain with molecular weight of about 25,000D are two types of protein found in cocoon silk. Both proteins are connected by a single disulphide bond and makes larger chains. Furthermore, an auxiliary protein named as P25 which assists conversion of the proteins to fibers.

8.6 Processing of silk

8.6.1 In Vivo processing
The synthesis of silk fiber is occurred in the glands of silk worms that are formed in their head or in case of spiders these glands are located in abdomen. In the glands of spider any change in physiological condition like change in pH of salts or content of water may affect the quality of fiber, it also effects the degree of crystallinity of fibers. In the case of silk worm three specific regions exists for glands and two different organs form thread like formation [22] [23]. The synthesis of fiber occurs in subsequent part of gland while the protein is moved by peristalsis-middle part of gland, and deposited as the viscous-aqueous solution that is required for the process of spinning. The concentration of protein in the posterior part of the gland is 12 to 15%, it is the part where the synthesis of fibroin chains occurs. In the middle region this concentration reached to the level of 20 to 30%, this the part where fibroin is stored and the synthesis of sericin occurs. While in the region of the gland where spinning starts the concentration is higher than the previous [23]. In the process of transition, the pH of the solution falls from neutral pH to pH5 at spinning point. Such changes are connected to precipitation of protein that occurs to enable the spinning of fibers.

8.6.2 Rheology
In the process of spinning, there is an important role of physical shear at the process. The shear is basically accountable for orientation of helicoidal liquid during last step. The rheological experiments show that the crystalline structure in fibers is positively correlated with draw rates and shear. The rate of shear observed to be more in frontal part of gland where dia. of gland is low (0.05 to 0.3mm), while water rapidly leave the gland, at this point pH decreases and the ion exchange occurs. Before the spinning viscosity becomes higher. Dragline silk by the spiders provide very less understanding about this phenomena. Ampullate glands are responsible for the synthesis of protein in spiders. More often the process is similar in spiders as the silk worm. In case of spider no sericin in involved in the process of spinning.

8.6.3 Solubilisation of silk
Due to the heavy hydrogen bonding, the extensive Van der Wall forces make silk fiber difficult to resoluble, and the elimination of water from the inter sheet parts. Silk from silk worms and spiders is insoluble in alkali, water, organic solvents and dilute acids. They are somewhat resistant to most proteolytic enzymes [24]. Degumming or removing sericin is the important process for solubilisation of silk worm fibers, this can be performed by using the solution of boiling soap or boiling solution of dilute sodium bicarbonate. The next process is emersion of the fibers in the salts of high concentration like calcium nitrate, lithium bromide or lithium thiocyanate. In case of spider silk these solutions does not always work. Instead higher concentrations of formic acid and propionic acid and hydrochloric acid mixture are used. When the solubilisation is done, dialyzing into water or buffering is used to remove the concentration of salts and acids [25].
8.6.4 New materials formed from reprocessed silk
After the solubilisation of different type of silks they are reprocessed into different new materials such as films hydrogels sponge materials etc.

8.6.5 Films and fibers
The films produced from water soluble protein, generally possesses a silk one conformation having a larger content of random coils. Variants of silks engineered genetically and resolublise silk worm cocoon silk are being spun into fibers [26] [27]. Such fibers tend not to show good mechanical properties in basic material. Electro spun silk is also generated by spider, silk worm and genetically engineered silk [28] [29]. The diameter of these fibers can range in hundreds and thousands of Nano meters, depends upon the spinning condition. Mineralization of fibers can be done for more stiffing of materials [30].

8.6.6 Hydrogels
This is another form of reprocessed silk [31]. These gels are prepared by aqueous solution of fibroin. Sol-gel transition method is used, the rate of sol-gel transition depends upon temperature. If the temperature is high there will be more rapid gelation. If the pH is low the gelation will be more. Rate of gelation can be enhanced by using cations, of specific salts selected according to the type of silk, Potassium for dragline silk and calcium for silk worm silk. Osmotic stress, morphology, mechanical and structural details have a strong impact on the rate of gelation.

8.6.7 Sponge materials
Sponge materials are 3D porous mediums, having controlled pore size, structural content and porosity. It can be made by organic solvent or aqueous process or by salt leaching or gas forming or else freeze drying systems [32]. Process used for the formation of 3D sponge materials has direct influence on its mechanical properties, cell and tissue formation and mechanical properties. There are different scaffolds used for this purpose. Pore size can be controlled using these scaffolds i.e. below 100 micro meters or more than 1000 micro meter.

8.7 Degradability
In textile forms silk fibers degrade on exposure to ultra violet light, as it has aromatic amino acid, phenylalanine and tryptophan in it. In biomedical applications e.g. sutures, silk fibers degrade slowly due to proteolytic degradation [33].

8.8 Applications
Silk fiber has been widely used in a wide range. Some of them are given below.

- Clothing industry
  Clothes that are made of silk are mostly expensive and have a high professed price. Dupioni is a category of Indian silk that is used in men’s and women’s clothing. Soft and elegant night gowns, robes and underwear are made by woven silk. Chiffon silk is light weighted and soft fabric, prepared from a yarn having high twist in it; it is high in strength but less in weight so used in formal suiting for women. Raw silk is frequently used in ladies outfits and activity coats, deposits of sericin in liquid form are present on the silk fiber and make it rough and coarse and forms “raw silk”. Women’s suits and coats and men’s sport coats are made with this silk.

- Home-based decoration
  Silk fabrics enhance grace and splendour to the scheme of most of the rooms.
  - Matka silk: Enhances thickness and texture to furnishing due to the amount of twist and fibers used in production.
  - Silk chiffon: Used to make ruffles for cushions and falling curtains.
  - Silk Wall: Wall coverings provide a good finishing to bedrooms and living rooms.
Silk fiber for household furnishings are mostly used in rooms that have less movement and wear, it is not stain resistant.

- **Some other uses**

Woven silk is used for the production of bicycle tires and parachutes. Silk fibers that go through a specific developing process, they are used for the construction of prosthetic blood vessels. A different use in the medical field is silk wraps for burns and wounds as silk exhibit good antibacterial properties. Many silk fibers are knitted into appropriate backgrounds for pen and ink paintings and drawings.

- **Blends with other materials**

Silk is also combined with other fabrics. Synthetic materials provide more stability to silk, as well as water spotting and sun resistance. For sports apparel, addition of cotton to silk fiber provides strength, resistance to stain and body to the fabric. Drapes and furnishings are also more strong and easy to take care, with synthetic fibers blended with the silk fibers. Silk can also be used as a high end wall covering.

- **Art-craft**

Because of silk’s texture and ability to take on vibrant colours, silk has been a used for beautiful tapestries and framed woven art for thousands of years, especially in the orient. The crafts like festoon, flower vase, wreath, pen stand, dolls, jewellers, wall hangings, clocks, bouquets and greeting cards can be carved using silk wastes. The silk based paper is used to craft flowers, buffet lamps and decorate plastics, steel and fabrics.
References


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CHAPTER – 9

9. Introduction

9.1 Man-made fibers
Fibers are generally classified into two major classes, Natural Fibers & Manmade fibers. Natural fibers are obtained by natural resources such as cotton, jute, flax etc., while synthetic or manmade fibers are produced artificially by polymerization process. During polymerization process we use different natural or synthetic monomers. This polymerization process is conducted during the spinning process by different techniques.

Natural fibers are environment friendly, low cost and abundantly available, but the fact is that their use in technical textiles is restricted due to their limited functionality. Consumption of natural fibers increased day by day and a big difference of ratios between the production and utilization occurred. So, to minimize this ratio, manmade fibers were introduced. Fibers or polymers with significant modification of chemical composition, structure and properties are known as manmade fibers.

Manmade fibers have different applications in every field of life due to its modified properties. These fibers have great importance due to their important role in high performance. There are different parameters for fibers such as they have sufficient length, strength, flexibility and adhesion to form a yarn. Diameter of these fibers should be in microns. Manmade fiber size is more uniform because we can control this during the production and we can select the production process according to our end product requirements.

Usually manmade fibers in bulk are produced by synthetic polymers. But these non-renewable sourced synthetic polymers have less feasibility as compared to renewable sources. If we compromise on natural fibers then it is possible that there will be not enough space for their production. So, it was diverted towards manmade fibers but for these fibers production there are many problems to face such as oil utilization, and the waste from manmade fibers industry that causes pollution.

9.2 Characteristics of fibers
Now a day’s technical fibers and nanotechnology have gained repute because of their high quality and modified characteristics. Some of the characteristics of fibers are described below;

9.2.1 Strength
Tensile properties are one of the major factors counted for a fiber quality. It is ability of a fiber to resist for change when subjected to a force. Long molecular chains are responsible for its higher strength, and length of the molecular chain is also termed as degree of polymerization.

9.2.2 Abrasion resistance
Abrasion resistance is the surface property of a fiber when subjected to rubbing. If the surface is smooth it gives good feel and resistance will be low. Some of the fibers are arranged as for their abrasion resistance: nylon, polyester, acrylic, wool, cotton, rayon, acetate.

9.2.3 Resilience
Resiliency is the elastic property of a fiber. Recovery of a fiber to its original shape when the force is removed is also known as resiliency. It is actually the property of molecular chains in fibers, crosslinking of these chains helps to stop the sliding of molecular chains.

9.2.4 Stability
Stability is another property of a fiber, it’s retention of sizes and a stable fiber can never be stretched or shrunk. A stable fiber is responsible for the stability of fabric.
9.2.5 **Cohesiveness**
Cohesiveness of a fiber is due to natural crimp, that is present in staple fibers but there is absence in filament. It’s the property to clutch together while spinning.

9.2.6 **Plasticity**
Moisture, heat or pressure enabled property of fiber to change shape permanently. Mostly this property is found in wool due to scales in its structure and has lack of stability. Fibers having this property are not washed in hot water because they are heat sensitive.

9.3 **Classification of manmade fibers**
When we discuss manmade fibers with detail then we came to know that they are classified into different types such as regenerated fibers, mineral fibers and non-cellulosic manmade fibers (figure 1).

Based on manmade fibers’ length and fineness, these are mainly distributed into four types

- **Staple fibers**
- **Filament**
• Filaments toe
• Nano fibers

9.3.1 **Staple Fibers**
Staple fibers are comparatively of short length, and if we discuss about natural fibers they range from millimetres and it ranges for cotton fibers 2-3cm, for wool it ranges 5cm.

9.3.2 **Filaments**
Manmade fibers and regenerated fibers are produced in the form of filaments. These fibers have unspecified length.

9.3.3 **Filament tow**
Synthetic fibers are mostly cut into short fibers and for natural fibers processing these fibers are cut into short fibers, it is known as filament tow.

9.3.4 **Nano Fibers**
These type of fibers are mostly spun through electro spinning technique. And their diameter ranges from 500nm. There is porous structure on the surface of nanofibers that can be functionalized for the drug delivery system.

9.4 **Regenerated cellulosic fibers**
All type of manmade fibers have some common process. Their production is based on non-fibrous material such as viscous solutions, gels or solid in molten form. This type of materials are passed through spinnerets and are converted into fibers. After leaving the spinnerets these are hardened and then winding in cone form is done.

9.4.1 **Rayon fibers**
Manufacturing of rayon is based on the regenerated cellulose based on some modification or by replacement of some hydrogen from the hydroxyl groups present. In the early research of rayon, it was the process to produce silk without silk warm. First of all, nitro-cellulose was produced successfully and was marketed commercially. Many of the developments were made in these fibers and rayon that includes viscous, Cuprammonium, Hydrolysed acetate, Nitro-cellulose is still a little bit similar to the original one. Usage of rayon is described as (figure 2)

![Figure 26: Percentage distribution of rayon fiber usage](image)
If we study its properties then we came to know that these fibers have no resistance to flame, these fibers burn with yellowish flame and grey ash is produced. Chemically these fibers are not damaged by alkali but are sensitive to acids. To enhance these properties these fibers are chemically treated.

According to its family name “regenerated cellulose fibers”, these fibers are obtained from cotton linters, and linters are the short fibers obtained from the seed surface. These short fibers are then treated with alkali (dilute NaOH solution) at a specific temperature and pressure. These conditions are dependent on the end product to be obtained. Then to stop the alkali action these fibers are washed in distilled water. Now bleaching is done and fibers are again washed then filaments are produced. Flow process of viscous rayon production is as (figure 3)

![Figure 27: Viscous rayon fiber production process](image)

Size of spinnerets and drawing are responsible for the diameter of fibers obtained. During the drawing, long chains of molecules are arranged and crystallinity of fibers increases which results in strength and rigid regions in fibers.

9.4.2 Acetate
Acetate is a cellulose based fiber, which is produced with the addition of glacial acetic acid, acetic anhydride, Sulphuric acid, acetone and water in purified cellulose. Including very good drape it has good look with soft, cool and smooth feel. Its colour is pure white but its colour changes to yellowish when exposed to sun light for long duration. It is heat sensitive but flammability is dependent on its structure, it has lower absorbency with specific gravity 1.32 g/cm3. It is used in sportswear, gloves, garments, curtains, blankets and comforters etc. it is also used in cargo, parachutes, fluorescent signals and in safety appliances.
Production of acetate is shown in (figure 4). To start the reaction for acetylation purified cellulose is moisturized in acetic acid. Acetylation process is done in acetylator closed tanks where the mixing and other process are done at temperature as per requirement.

![Diagram](image)

**Figure 28: Acetate fibers production**

### 9.5 Mineral fibers

#### 9.5.1 Glass fibers
Glass fibers are silicon based inorganic polymeric fibers, which are obtained from sand, silica, lime-stone with addition of boric acid as major components. Raw material is melted in a furnace having temperature more than 300 °F to form a viscous homogenous solution for further processing.

Finishing is done to increase the fibers surface resistance, this process is called coronizing. In 1\textsuperscript{st} step heat treatment is done to remove the volatile impurities and to remove any type of tension, then in 2\textsuperscript{nd} step finish is applied.
It has different characteristics such as higher strength, brittle structure due to crystalline regions and it has very low folding characteristics, it has water repellant nature. It is colourless including high resistance to acids and alkali.

9.5.2 Asbestos fibers
Asbestos is mineral based fiber, these fibers are obtained by crushing the rocks and then fibers are collected according to our requirements (length). Length exists in between 3/8”-3/4” having white or grey colour. Their microscopic view informs that these are small rods with smooth surface. Asbestos fibers have good wicking properties including absorbency, and are used in fire proof clothing for protective purposes. There are used in conveyer belts, aprons, gloves and laundry presses etc.

9.6 Non-cellulosic manmade fibers

9.6.1 Nylon
In nylon structure, there is no side linkage but the straight aliphatic chains of polyamides are present. It is made by the combination of carbon, oxygen, hydrogen and nitrogen atoms. The aliphatic chains are closely packed to each other, those results in smooth surface. Polymerization of hexa-methylene diamine and adipic acid is done through condensation polymerization, and the water is by product (figure 6)
Characteristics of nylon are dependent upon the conditions such as spinnerets size, drawing ratio and temperature. As orientation of long chains is done during the drawing so we can adjust the crystallinity and amorphous region as per requirements.

Nylon has lustrous surface depending upon the degree of crystallinity. It has higher strength with 18-37% elongation, and low absorbency including 1.1-1.4 g/cm3 specific gravity. It is not sensitive to coldness but its characteristics changes at high temperature. It has very good wrinkle resistance, abrasion resistance and crease recovery. It has also very good elastic properties. It degrades and loses its strength when exposed to sunlight.

Figure 30: Process flow chart of Nylon fibers
9.6.2 Acrylic fibers
Acrylic fibers are produced from acrylonitrile polymers. Depending upon the percentage of acrylic group these fibers are classified into different types;

- Orlon
- Acrilan
- Creslan
- Zefran
- Modacrylics (Dynnel, verel)

By addition polymerization of acrylonitrile Orlon is produced. Near about 2000 units are combined by hooking of polymer. There are no side chains in Orlon. Production flow diagram is shown below (figure 8). Spinning solution for acrilan is dimethyl acetamide, obtained from copolymer of acrylonitrile and vinyl acetate that is in white powder form. Creslan is an acrylic fiber in range of 1\textsuperscript{1/2}-6" length. This type of fiber has good affinity for dyes as compared to other acrylic fibers. Zefran is made of by combining acrylonitrile and other substances in limited amount. It is relatively less heat sensitive.

![Flow chart of Orlon fibers production](image)

**Figure 31: Flow chart of Orlon fibers production**

Some of the properties of acrylic fibers are,

- These fibers have suitable strength.
- These fibers have good recovery properties.
- Low to medium water absorbency.
- These fibers have soft feel just like silk and wool.
- Heat sensitivity is also low to medium.

9.7 Spinning techniques of manmade fibers
There are different spinning techniques for different types of material. A basic flow chart is as;
There are different steps involved in fibers development, 1st of all spinning polymer is prepared, 2nd this polymer is passed through spinnerets, 3rd these fibers are stretched to rearrange the polymer chains to increase its strength.

Some of the different techniques are as:

1. Wet spinning
2. Dry jet wet spinning
3. Melt spinning
4. Gel spinning
5. Electro spinning

Firstly, the polymer that is being formed is converted into the molten or in solution form before the fibers formation. If the material is thermoplastic than it can be melted and by melting convert into the liquid state. If there is thermosetting material then it is converted into liquid form by making the solution and prepared the dope solution. Now it is done that thermoplastic will be in molten form and thermoset will be in solution form. Because thermosets are degraded before reaching the molten form so they are used in making the solution for spinning.

The molten material is pressed through the spinnerets and then cools so this will convert into the rubbery form and on more cooling, this will convert into the solid form. And in case of solution form solvent that is used in the solution is removed by different techniques and by this polymer is solidify.

There are different techniques for spinning of manmade fibers.

9.7.1 Wet spinning

Wet spinning is one of the oldest methods that are used for the spinning techniques. For this firstly we made the solution and for this we stir different materials till they are dissolving equally. When they dissolve equally and we attain the chemical solution we put it in the box of machine or we say it as a tube then we create pressure because we press this solution to pass through the spinneret so after giving the pressure we press this solution and spinnerets of our choice are fitted on the extraction position. Now these fibers are in liquid form we put these fibers into a bath and this is the reason for which we called it wet spinning. This bath will solidify them and put it on
different routes of rollers for stretching of the fibers. To reduce the amorphous regions, the drawing process is deployed and a good level of crystal region is achieved. Different types of fibers are prepared through this technique which is given below

- Aramid
- Spandex
- Acrylic
- Rayon
- Mod acrylic

In this technique fibers are solidified direct extrusion and put in the liquid bath. There is a slightly different technique is used that is dry jet wet spinning and in this technique, we do not put the extruded material direct into the liquid bath, we give a gap in between the extruded material spinnerets and liquid bath. We did this task because of making more crystal region that is formed through wet spinning because when we give gap then the material has a chance to be aligned so it is more efficient than wet spinning.

![Figure 32: Wet spinning](image)

There is coagulating bath in wet spinning and extruded material will go directly in the bath. There are different shapes of spinnerets are used for the spinning on their requirement. It is very important for their mechanical properties. Mostly circular type of spinnerets are used.

9.7.2 **Dry-jet wet spinning**

The main thing in the dry jet wet spinning is that it has gap between the extrusion point and coagulating bath. So, time is provided through this process to be more or highly align. Previous fibers are prepared through this process because of formation of same solution. And the
interesting thing is that coagulating material will remain same. These machines are broadly used in European countries but in Pakistan it is used only in experimental way.

It has also spinnerets of different size with different shapes. The size determines the count, shape and its fineness. It is very complex to make the spinnerets of this machine because they are so small and solution should be so highly dispersed that a little or Nano sized material will block the spinneret and stop the extrusion through this hole. So, this hole is opened again by burning off the material or some other techniques.

9.7.3 Dry spinning
Dry spinning used for the material that is dissolved in the solvent, because of the dissolving in the solvent its spinning is impossible and it is same solution in looking vise as above but very different nature solution because you see in the previous case when solution extruded in the coagulating bath then its convert into precipitate and get solidified but here is different in dry spinning you made a solution in a solvent that is low volatile and can easily remove by this solution leaving the solute so when you extrude the material then hot air is blown through these fibers who remove the solvent and the material get solidified. In the place of hot air, we can use the inert gases that also do the same thing as hot air. In dry spinning material is like that it has no need to match with other till its extrusion and when it is extruded then its need vanished and you can remove its solvent and in this technique, there is no need to dry the fibers because of they get dried on blowing air or inert gases.
Different types of fibers are extruded through this machine like, Acetate, polybenzimidazole, triacetate, vinyon, Acrylic, spandex, modacrylic are prepared through this process.

**9.7.4 Melt spinning**

The polymers that do not decompose before melting are used in melt spinning. Like in the previous spinning techniques they degrade before reaching to the melting temperature so they are spin by converting the material in the solution form. Naturally some polymers can melt and spin through this machine. So, to operate this machine first we give the heat to the polymer material and melt it then give the pressure to pass through the path and then cool down to solidify this is the melt spinning. Here are also spinnerets are used in the melt spinning. These are also different shapes and sizes are available in the melt spinning.

The fibers formed through this technique are given below

- Saran
- Nylon
- Sulphur
- Olefin
- polyester

There are different two types of melt spinning.

- Extrusion Melt Spinning
- Direct Melt Spinning
9.7.4.1 Extrusion Melt Spinning
This melt spinning has characteristic of first melt the pellets and then make fiber through this material. In this case first we have to make up the pellets that can be used at the time of your choice and melted pellets are pressed through the spinnerets and extrusion is done. Now we give cooling to this extruded material to solidify. By this we attain the final fiber.

9.7.4.2 Direct Melt Spinning:
In this technique, there is no use of pellets and we melt the polymer directly and when we get the melt material then extrude it from the spinnerets this is direct melt spinning. Direct spinning is used in formation of polyester mostly.

9.7.5 Gel spinning
Another spinning technique where some specific characteristics with better strength are required. In this technique spinning solution is used in gel form, and gelation is attained when we make a solution of a polymer with maximum concentration. In this form, polymeric chains are partially bonded with each other. When this gel is extruded in fiber form then there is maximum bonding between the polymer chains along with maximum degree of orientation. Most of the fibers with higher strength are made through gel spinning, such as aramid fibers and polyethylene fibers.

9.7.6 Electro spinning
Mostly electro spinning technique is used for the formation of nanofibers. There are mostly three main components:
- Syringe pump
- High voltage supply
- Opposite charge on collector
Critical voltage value depends on the solution properties such as molecular weight and viscosity. When solution under goes high voltage then elongation increases and fibers become very thin and large.

Many of the parameters have direct influence on the surface structure of electro spun nanofibers. These parameters are classified as;

- **Solution parameters**
  - Concentration
  - Molecular weight
  - Viscosity
  - Surface tension
  - Conductivity
- **Processing parameters**
  - Voltage
  - Flow rate
  - Collector
  - Distance
- **Ambient parameters**
  - Increasing temperature decreases the thickness
  - High humidity will lead to thick fibers

![Diagram of Electro-spinning Process](image)
10. Regenerated fibers

10.1 Introduction
This deposition of data is made for understanding the regenerated cellulosic fiber's production process and their properties with relation to their end use. Basically, all the regenerated fibers are made from cellulose as a basic monomer, while using manufacturing techniques like synthetic fibers. It is found from the study that regenerated fibers of 2nd and 3rd generation have good strength, softness and parameters related to moisture management properties. These fibers are therefore preferred in apparels. Regenerated cellulosic fibers are having very low impacts on the environment as compared to the cultivation process of natural fibers therefore now these fibers are getting their special place in the market.

10.2 Bamboo Fibers
History of bamboo tells about its utilization from a huge number of years; however, utilizing in a fabric is its innovation. Truly, the most adaptable thing that could be produced using bamboo was paper, which was invented in China hundreds of years ago. Bamboo, among different materials, was utilized as a part of the development of a few sorts of this early paper[1]. Bamboo was utilized for different things other than paper among that time, including houses, weapons, needles etc. Bamboo is quickest developing woody plant on this planet. It grows 33% quicker than the quickest developing tree. Bamboo and its related businesses provide money, food and lodging to more than 2.2 billion individuals around the world.

Essentially bamboo filaments are cellulose based recovered fiber removed from the common development of bamboo, and are the fifth regular strands taking after the cotton, material, wool, and silk. It is biodegradable material. As a characteristic cellulosic fiber, it can be 100% biodegraded in soil by microorganism and daylight[2]. Its deterioration procedure doesn't bring any contamination in environment. Bamboo fibers can be achieved by two methods direct from the bamboo Culm by removing non-cellulosic parts. Thel other way of its production is like rayon by dissolution of wood pulp in the chemicals and then extrusion and evaporation or removal of chemical from the fibers. Fibers of bamboo are not a much stronger as other regenerated fibers. Due to less strength, they are mostly tried to use in the knitted products because in knitting production of fabric process yarn has to bear less forces and less abrasion.

10.2.1 Production Process of Bamboo Fibers
Bamboo fibers are basically regenerated fibers which are manufactured by getting raw material or basic polymeric unit from bamboo plant that is based on cellulose and then further processed like rayon fibers to make bamboo fibers. There are mainly two process of bamboo fiber production,
Bamboo fiber Production Process

Chemical Process
- Preparation
- Steeping
- Pressing
- Shredding
- Ageing
- Xanthation
- Dissolving
- Spinning

Mechanical Process
- Retting
- Enzymatic Process
- Chemical Process
- Breaking
- Scutching
- Hackling

Figure 37: Bamboo fiber production process

10.2.1.1 Mechanical Process:
Mechanical process of obtaining bamboo fibers from stalk of bamboo plant is almost like the process of flax fiber. Different steps of mechanical process are elaborated briefly.

Retting
Retting is the process of loosening of internal compact structure of bamboo stalk. In this process stalks are placed in water solution in which fibers are loosened from woody stalk of bamboo[3].

10.2.1.2 Enzymatic Process
This process involves activities of enzymes on the bamboo stalk, which help to remove woody material from fibers.

10.2.1.3 Chemical Process
Fibers are boiled in mild acid or alkali making it resistant to the effect of microorganism and bacteria & removal of lignin and gums from fibers.
Breaking
Fibers are separated from stalks.

Scutching
Extraneous material like gums, woods and other parts of structure are removes from fibers.

Hackling
Aligning of fibers in one direction is called hackling.

Mechanical process is time taking and labour-intensive process. Because original fibers from stem are achieved which needs a lot of precautionary measured for getting maximum length of fiber. It is a time taking because by the effect of chemicals and mechanical process fibers are separated which runs very slowly due to mild chemicals. Otherwise strong chemicals will deteriorate the properties of fibers.

10.2.1.4 Chemical Process
Chemical process is like the process of other synthetic fibers but its raw material is extracted from natural source[2].

Preparation
First step of bamboo fiber formation is preparation in which inner soft portion of bamboo trunk and leaves are extracted and crushed for ease of process.

Steeping
In steeping process, all the crushed material is dissolved in 20% solution of Sodium Hydroxide (NaOH) Alkali at following parameters to form alkali cellulose.

Temperature 20°C-25°C
Time 1hrs -3 hrs

Squeezing/Pressing
In this process, the dissolved bamboo pulp is squeezed or pressed by mechanical means to remove the excess amount of NaOH.

Shredding
Shredding is the process in which dissolved material is minced out or homogenized for making it easier to process.

Ageing
Ageing is the process in which the shredded pulp of bamboo is dried up in air for at least 24 hours. During this ageing process, the pulp encounters air and cellulose is oxidized which in return gives lower molecular weight of cellulosic chains. Due to lower molecular weight required viscosities are easily achieved in the spinning process.

Xanthation
In this process carbon sulfide is added in the bamboo alkali solution to make it jelly like. After that carbon sulfide is evaporated and remaining is sodium xanthate.
Dissolution

In sodium xanthate, a dilute solution of alkali (NaOH) is added to dissolving it and making a viscose solution in which 5% NaOH and 15% bamboo fiber cellulose is present.

Spinning

After successive ripening, filtering, degassing the bamboo cellulose is passed through spinnerets and received in a dilute sulphuric acid solution. In sulphuric acid solution viscose bamboo cellulose is hardens and converted in pure bamboo cellulose fiber and then spun in to bamboo yarn.

10.2.2 Properties of Bamboo Fibers

Bamboo fiber is known for its softness and inherent anti-bacterial property. Some physical parameters of bamboo fiber are shown in tabular form below[4][5].

Table 9: Physical Properties Comparison of Bamboo

<table>
<thead>
<tr>
<th></th>
<th>Bamboo</th>
<th>Cotton</th>
<th>Lyocell</th>
<th>Viscose</th>
<th>Modal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Tenacity, cN/Tex</td>
<td>22-25</td>
<td>20-43</td>
<td>37-45</td>
<td>18-26</td>
<td>24-36</td>
</tr>
<tr>
<td>Wet Tenacity, cN/Tex</td>
<td>13-17</td>
<td>27-56</td>
<td>30-39</td>
<td>9-15</td>
<td>12-24</td>
</tr>
<tr>
<td>Elong. At Break, %</td>
<td>14-24</td>
<td>6-10</td>
<td>12-16</td>
<td>15-25</td>
<td>13-25</td>
</tr>
<tr>
<td>Moisture Absorption%</td>
<td>13</td>
<td>7-8</td>
<td>11-12</td>
<td>10-16</td>
<td>12-13</td>
</tr>
</tbody>
</table>

From the above stated properties of bamboo fibers as compared to the other regenerated fiber. Dry tenacity of fiber is almost moderate as compared to other regenerated and natural cotton fiber. But it is having equal or higher moisture absorption content.

Tensile Strength

Some species of bamboo fiber has very high tensile strength like steel[6]. Modern production processes allow formation of yarn and bamboo fabrics. Fabrics which are made from bamboo fiber are very durable due to high strength.

Anti-Static

Bamboo fibers are naturally anti-static

Ease of Dyeing

Bamboo fiber is originated from cellulose therefore it is very easy to dye. Its colour absorbing capacity is also very good. Natural colour of bamboo is light yellow colour or cream colour.

Crease Resistance

Bamboo fiber has high weight as compared to cotton and is thick. Due to thickness, it has more ability to resist creases in fabric. But it is comfortable to wear at the same time.

Anti-allergic

Bamboo fibers are naturally anti-bacterial and it has well anti allergic property for sensitive skin persons.
Environmental friendly

Bamboo is environmental friendly fiber and it is also bio degradable

UV Resistance

UV property of Bamboo fiber is inherent. It decreases the effect of sun light. It is best for summer wear and sensitive skin[7].

Breathing Fiber

Bamboo fiber is asked breathing fiber by the experts due to its high air permeability. It is due to hollow structure in horizontal direction.

10.2.3 Applications

10.2.3.1 Conventional Application:
Bamboo fibers are made from pure bamboo pulp due to which it shows greater vapours transport, drape, permeability, softness and good dye absorption properties. Moisture content in the bamboo fiber is highest as compared to all other natural fibers. Owing to these properties it is used in following [8].

Intimate Apparels

Apparels from bamboo fiber include sweaters, t shirts, underwear, socks, mats and bath suits. Due to good lustre dye absorption, it gives good appearance in apparel. Other than these properties it has an excellent property of UV radiation. Mostly summer clothing of pregnant women and children is done with bamboo fiber to give both UV resistance ad anti-bacterial property in the garment.

Bamboo decorating series

Bamboo enhancing arrangements have the elements of antibiosis, bacteriostasis and bright verification. They are exceptionally profitable for use in the finishing industry. Alongside the severely decay of air contamination and the decimation to the ozone circle bright radiation beams are more and that's only the tip of the iceberg turning into an issue for individuals. Long-time introduction to ultra violet radiation will bring about skin growth. Backdrops and drapes produced using bamboo fiber can retain bright radiation in different wavelengths along these lines they reduce the trouble to the human body. More essential, bamboo improving items won't go mildew covered because of moist.

- Window ornaments
- TV covers
- Backdrops
- couch slipcovers

All these can be produced using bamboo strands.

10.2.3.2 Technical Application:
Nonwoven applications

As a natural and green fiber due to its 100% biodegradability it is used in the non-woven technical applications[8]. Like in medical personal care, wound dressings, masks, surgical caps, gowns, mattress, bed linen, sanitary napkins and in food containing bags due to anti-bacterial nature.

Bamboo Personal Care Products
In view of the normal antibiosis capacity of the bamboo fiber the wrapped-up items require no including of any manufactured incorporated antimicrobial operator. Hence bamboo fiber items won't bring about skin sensitivities ad at the same time it has an upper hand in the market.

Bamboo Fiber based Composites

Bamboo fiber has strength almost high specific strength equivalent to conventional glass fiber[9]. Bamboo fiber is therefore used in eco-friendly and bio degradable composites. Some of them are also used for the medical use in support of broken bones instead of steel plates.

10.3 Tencel Fibers
Tencel fiber is considered as third generation fiber in the race of regenerated cellulosic fiber. One step back from Tencel is Modal fiber. The basic needs behind the production of Lyocell fiber was using the renewable resources and use of environmental friendly production process. It was commercially produced by Courtaulds United States in 1992. They were international supplier of viscose rayon[10]. Then Lenzing AG had acquired patent on that and start the further research in this area. Then Lyocell was recognized in the apparel market, designer's suits and high-end garments. It is very desirable having both functional and aesthetic properties at the same time.

Lyocell is 100% cellulosic fiber made from the wood pulp. At first hard wood of Birch was used but now Eucalyptus forests are used by Lenzing AG to produce fiber. Tencel Lyocell fiber is produced by making pulp of wood in amine oxide and by following its subsequent steps. At the end amine oxide is totally recovered and reused. That is why it is considered environmental friendly produced fiber. It is very versatile fibre with very good properties. It is used in very light fabric range from blouses of women to very heavy fabric range of men suits. It has applications in woven as well as in non-woven industry also.

Lyocell is beneficial because it is fully biodegradable and is also beneficial because of properties like absorbency and its feel and handle can also be changed by using different finishes on it. It has highest strength in both wet and dry state. Therefore, it is easy to spin it into very fine yarn and very light weight fabrics. Due to high strength, it is easy to handle in different chemical and mechanical process of finishing. It also gives excellent blends with cotton, wool cashmere etc. due to its excellent properties. But there is a significant area of research to control the fibrillation in Tencel fiber. It is a subject of great interest, because fibrillation process causes the small fiber's one end to be detached from the yarn and it protrudes on the surface of the yarn or fabric. Fibrillation is high in Tencel as compared to cotton, which results in loss of its strength in some cases[11].

10.3.1 Manufacturing of Tencel Fiber
Manufacturing process of Tencel fiber is totally ecological and non-toxic process. It does not involve any toxic chemical. Flow chart of its process is elaborated below[12],
10.3.1.1 Preparation of Wood Pulp
Special plants are grown for Lyocell like Eucalyptus, birch is cut into logs and then debarked with high pressure water jets. After debarking of logs, they are cut into small pieces of almost 1-inch square area. These small chips of wood are mixes in a chemical container which softens the wood into pulp. After proper solving of chips in chemical it is squeezed out and dried.

10.3.1.2 Dissolution of Cellulose
Dried pulp is then mixed with a pressurized, heated tank of amine oxide.

10.3.1.3 Filtration
Filtration is done on the cellulosic solution to make sure that there is no woody matter present in the pulp mixture and extra chemical and water solution is filtered from the pulp.

10.3.1.4 Spinning of Fibers
Filtered pulp is then passed through spinneret, which contains small holes like a shower head. Cellulose in the form of thin strands comes out from spinneret and these fibers are then passed from a bath of dilute amine oxide. In the bath of amine oxide cellulosic fibers are set down and then washed with de-mineralized water.

10.3.1.5 Washing & Drying
These strands are washed with distilled water and then dried up by evaporating the amount of water from it. After drying these fibers are finished with some suitable materials considering the future use of fibers and their spinning process. Mostly, the finishing material is used as a detangle material for fibers to make its spinning into yarn an easy process.
10.3.1.6 Recovery of Solvent
Amine oxide used as solvent in dissolution of cellulose and setting of fibers is recovered after drying. The water is evaporated and the remaining amine oxide added again into the process of manufacturing of Lyocell. Almost 99% of the Amine oxide is recovered in the process.

10.3.2 Structure of Tencel Fiber
Structure of Tencel fiber is highly uniform. Fibers are circular in diameter[13].

![Circular Structure of Tencel](image)

Figure 38: Circular Structure of Tencel

10.3.3 Properties of Tencel Fiber:
A manmade regenerated cellulose fiber Lyocell has excellent properties among all the cellulosic fibers. It has excellent moisture absorption, cool and can be textured like cotton and wool. It is like rayon fiber in drape and has strength like polyester. Some Physical and chemical properties of cellulosic Tencel fiber are discussed below[14].

10.3.3.1 Physical Properties

<table>
<thead>
<tr>
<th></th>
<th>Cotton</th>
<th>Bamboo</th>
<th>Lyocell</th>
<th>Viscose</th>
<th>Modal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Tenacity, cN/Tex</td>
<td>20-43</td>
<td>22-25</td>
<td>37-45</td>
<td>18-26</td>
<td>24-36</td>
</tr>
<tr>
<td>Wet Tenacity, cN/Tex</td>
<td>27-56</td>
<td>13-17</td>
<td>30-39</td>
<td>9-15</td>
<td>12-24</td>
</tr>
<tr>
<td>Elong. At Break %</td>
<td>6-10</td>
<td>14-24</td>
<td>12-16</td>
<td>15-25</td>
<td>13-25</td>
</tr>
<tr>
<td>Moisture Absorption%</td>
<td>7-8</td>
<td>13</td>
<td>11-12</td>
<td>10-16</td>
<td>12-13</td>
</tr>
</tbody>
</table>

Texture
- Soft leather like touch
- Very comfortable for sensitive skin
- Due to good wicking property keeps skin cool and dry

Strength
- High tensile strength as compared to natural fibers
- Very high strength when it becomes wet

Moisture Absorption
- High absorbent of moisture
- Very good breathability and 50% more moisture absorbent than cotton
- It readily swells on wetting
The basic mechanism behind the very good absorption of water in the Tencel is having porous structure or nano structure at fibril level. Its behaviour is unique among the all cellulosic manmade fibers. The small crystalline fibers are arranged in very regular manners. Fiber themselves do not absorb water; in fact water absorption is take place between the capillaries of fibers[14]. A single wet fiber of Tencel behaves as a strand of fibers. It is totally due to the porous structure of Tencel fiber which is not present in synthetic fibers world.

Bio-degradable

It is cellulose based man-made fiber. Due to natural raw material, it is fully bio degradable in to nature

Dimensional stability

- Low shrinkage
- Good wash ability, can be washed with hands

Thermal Insulation

In case of thermal insulation, Tencel is one of the best materials. It is a unique fiber which gives a lot of other properties regulation at the same time with insulation property.

Tencel filling in the Duvets gives very good thermal insulation as compared to polyester fillings and down filling. It also maintains water vapours transport and very goof moisture absorbance at the same time.
Basically, thermal absorptiveness of materials is the property of material to absorb heat and carried away from the body. Due to which wearer feels cool and dry. The above shown graph elaborates the thermal absorptive properties of pure cotton and blends with Tencel at different humidity level. From the graph, T.A is gradually increasing with the increase of Tencel percentage in the sample blend.

Natural Anti-Bacterial

It is considered natural anti-bacterial because when it absorbs 60% water, all the water contents are totally absorbed in the fiber, and there is no moisture/water on the surface of the fiber, while it is necessary for the growth of bacterial on a material to get a film of moisture on the surface.

Dye Absorption capacity

Lyocell absorbs more dye even it has highest crystalline structure among all other regenerated fiber.

10.3.4 Applications

10.3.4.1 Conventional applications

In conventional term Lyocell is mostly used in apparels, home textiles. Some of its area of use in apparel is,

- Denim
- Suits
- Casual Cloth
- Under Wear
- Shirts
- Knitted apparel
- Denim in Lyocell

Lyocell fiber is almost two times stronger than cotton. Lyocell used in jeans gives better comfort properties and stronger garment. Denim jeans used in sports can be very useful in sense of
comfort and moisture management and soft touch to the skin[14]. Due to good drape property of Lyocell fiber its jeans and other garments give good body shape and proper fall with wearer body. It is also very light in weight as compared to cotton jeans.

Kids Wear

The combination of properties in the Lyocell fiber essentially makes it perfect for child's wear. Child's skin is delicate and touchy and requests the absolute best materials. Lyocell offers the greater part of the properties such a great amount popular by the delicate skin of Youngsters. Carry out dampness administration combined with skin-tactile properties is critical in the clothing alongside kids' skin.

Lyocell's smooth fiber surface averts aggravations to the skin. Lyocell's virtue is another advantage since it is not defiled with horticultural chemicals. The ideal dampness administration of Lyocell can assimilate 50% for every penny more dampness than cotton, consequently supplies a characteristic cleanliness[15]. Because of the especially high dampness retention of Lyocell, the development of microscopic organisms can be stopped from the beginning. The dampness is transported from the skin straightforwardly into within the fiber. In this manner no film of dampness, which can be the reason for bacterial development, shapes on the fiber.

Lyocell Towels

The blend of comfort and performance of Tencel textures is currently empowering them to develop in both family unit materials and work wear applications. Alluring towelling textures are being advertised that adventure the fabulous water receptiveness, profound coloration and wet strength of Tencel.

Home Textiles

The Tencel fiber is utilized as a part of numerous applications focusing on beds – beginning with sleeping cushions and bedding covers through to sofa-beds and bed cloths[14]. At the point when utilized as a part of bed cloths, the Tencel fiber properties are flaunted to specific favourable position. Since the texture is in direct contact with the skin, solace is improved by Tencel's brilliant skin-tangible properties and unrivalled dampness administration.

Lyocell Duvets

In the form of blend of hollow polyester and Tencel fiber is used in duvets and quilts. Hollow polyester work as good thermal insulator for winter season, while soft touch of Tencel and its best moisture management properties give warmth and comfort to the user

10.3.4.2 Technical Applications

Nonwoven applications

It is used on nonwoven due to its high strength high absorbency, biodegradability and easy processing. Mostly its webs are formed by air laid or card process then those webs are bonded by some mechanical processing or chemical processes. By using needle punching, spun lacing, thermal bonding mostly webs are bonded. Main products which are formed the nonwoven process of Tencel is:

- Floppy Disk Liners
- Filters
- Surgical Swabs
- Drapes, Gowns
- Lining Materials
- Semi-Disposable Work wear
- Baby Wipes
- Bandages
Use in Paper

Tencel or Lyocell is used in the production of paper. Paper of high strength and high absorbency are made by it. High strength of paper is produced by the creation of fibrillation in the fibers. More strength would be produced if more fibrillation will be produced. Mostly high strength, low resistance to air due to circular structure of fibers and highly absorbent paper is produced.

Cigarette Filter

Cigarette filter are made by Tencel Fibers. Due to round fiber structure they are packed closely to each other and give high filtration properties. they blocks the extra particles in air due to high fibrillation they also stop the particles of air[16].

Conveyor Belts

Due to high strength and natural fiber as biodegradable fiber they are used in industrial applications of some types like in conveyor belts.

Carbon Shields

Tencel finer is used in carbon shields in different woven and nonwoven forms.

Capacitor Separators

Nonwoven fibrous separators are used in capacitors made of natural fibers.

Shoes

Tencel fibers due to their naturalness and good moisture management property are used in the upper layer of shoes and foam and also used in shoe laces[17].

Ropes & Twines

Agricultural ropes for support purpose are a future of Tencel. Tencel is a preferred material due to its good strength and biodegradability property[17].

Technical Knits

Tencel fiber is now used in technical knits in replacement of polyester fiber. Technical knits are mostly in those areas like chairs, upholstery because as compared to polyester Tencel is gentle to skin[17].
10.4 Modal Fiber
Modal fiber is a wood pulp based cellulosic fiber and beech tree wood was used for its production, while rayon is a fiber which is made from wood pulp of various trees. But when modal was produced it was known as modified viscose rayon but even modal has higher wet modulus and strength than viscose fiber[10]. Staple modal fibers were produced first time in 1930 for industrial used making their blends with fast growing synthetic fibers. With the passage of time betterment in production process of viscose make it high crystalline and high strength fiber following those developments in 1951 in Japan new developments were made and modal fiber was produced known as polynosic fibers[18].Modal fabrics are mostly used by designers due to their appealing properties softness, lustre and good drape.

10.4.1 Manufacturing Process
Modal fiber was made after viscose rayon therefore it was also known as modified viscose for some time. Its manufacturing process is also little bit different than viscose in just two steps and produced by wet spinning process. Manufacturing process is containing following steps[10]:

10.4.1.1 Steeping and Pressing
Process of steeping is done to make a solution of 17% alkali and pulp. When pulp is steeped in the alkali solution it swells and makes sodium cellulosate. Then the slurry made up of alkali and pulp is pressed to extract out the extra alkaline solution.

10.4.1.2 Shredding
Alkaline slurry contains here almost 36% Cellulose and 17% soda in the solution. This slurry is tattered so that oxygen and carbon disulfide could penetrate in it for forth coming mercerizing and Xanthation processes.

10.4.1.3 Mercerizing
Mercerizing is the process in which extra lustre is imparted to the fiber. Also, depolymerisation of cellulose id done here.

10.4.1.4 Xanthation
Here the slurry is made to react with fumes of carbon disulfide in vacuum to make sodium cellulose xanthate. For getting desired percentage of soda and cellulose in the fiber slurry is dissolved in the sodium hydroxide solution and it forms sodium xanthate.

10.4.1.5 Filtration
In this step filtration of solution is done to remove the large particles or anything which can act as impurities and block the spinneret holes. On this stage, also de aeration is done by creating vacuum so that air can be removed which can cause air bubbles in the fiber formation process.

10.4.1.6 Spinning
When fibers are formed by the liquid crystalline solution of cellulose they are high modulus and high tenacity fibers. In the Modal fiber process use of zinc in the spinning bath is removed to make the process eco-friendly. Fiber is passed for very short period of time from very low acidic bath, and then collected.

Coagulation Bath

In the process of modal fiber coagulation and drawing of fibers occur at the same and resulting of high wet modulus fibers.

After Treatment

After that fiber are dyed and washed and treated in gaseous environment to give them high sheen and glossy surface.
Diagrammatic Depiction of Process

Figure 41: Modal Fiber Manufacturing Process

10.4.2 Properties of Modal Fiber
Like other regenerated fiber modal is also a regenerated fiber having marvellous properties in its group. Modal is the second generation of regenerated cellulosic fibers after viscose. It is having viscose like properties but in some where it is superior to viscose like in moisture absorption strength and some other. Some physical properties of modal are elaborated in the table.

Table 11: Physical properties of Modal Fiber and comparison

<table>
<thead>
<tr>
<th></th>
<th>Modal</th>
<th>Viscose</th>
<th>Cotton</th>
<th>Bamboo</th>
<th>Lyocell</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dry Tenacity, cN/Tex</strong></td>
<td>24-36</td>
<td>18-26</td>
<td>20-43</td>
<td>22-25</td>
<td>37-45</td>
</tr>
<tr>
<td><strong>Wet Tenacity, cN/Tex</strong></td>
<td>12-24</td>
<td>9-15</td>
<td>27-56</td>
<td>13-17</td>
<td>30-39</td>
</tr>
<tr>
<td><strong>Elong. At Break, %</strong></td>
<td>13-25</td>
<td>15-25</td>
<td>6-10</td>
<td>14-24</td>
<td>12-16</td>
</tr>
<tr>
<td><strong>Moisture Absorption%</strong></td>
<td>12-13</td>
<td>10-16</td>
<td>7-8</td>
<td>13</td>
<td>11-12</td>
</tr>
</tbody>
</table>

High Strength Fiber

Modal fiber is high strength fiber in conditioned form. Therefore, after conditioning it is used different technical application just like tire cords it is used due to its aspect of bio degradable.

Comparison of its strength in conditioned form[19].
Figure 42: Conditioned & Wet Strength of Modal in Comparison

Wonderful Lightness

Lenzing Modal® micro fibers Micro Moda&micro fibers Micro Modal® and Micro Moda&micro AIR, fiber are very fine and light weight fibers.

Hygroscopic

It is highly hygroscopic. It absorbs water 50% more than cotton but it is as strong as polyester.

Dimensional Stability

It retains good dimensional stability even after having softest nature fibers

Pilling and dye ability

Modal fiber is less prone to pilling as compared to cotton. While, in case of dyeing it takes amount of dyes and its working is same as cotton. Good dye ability

Mildew Affects

As compared to cotton is has less effects of microorganism. Also, less ageing occurs in it.

In Blends form

Modal fiber is mostly used in blends form for getting some dual properties like[18]:

Modal/Cotton

Modal and cotton blends are used because both are natural cellulosic fibers and give softness and moisture absorbance, also they give equal lustre and drape.

Modal/Wool

Modal and wool blend is used for getting insulation property and warmth while at the same time modal imparts softness and skin friendly environment to the user.

Modal/Acrylic

Modal and acrylic blend is used for softness, lustre and silk like appearance of the fabric.
Modal/Tencel
Modal Tencel blends give extra handle, comfort and dimensional stability in the fabric.

Modal/Polyester
Used mostly for getting better fitting, good dimensional stability, brightness, soft handle and good drape.

10.4.3 Applications of Modal Fiber
Modal fiber is widely used in the apparel industry due to its eco-friendly and skin friendly behaviour. Especially in summer wear it works best. Some major application areas of modal are discussed below,

10.4.3.1 Conventional Applications
Clothing
Due to very soft and light weightiness and more important moisture absorption property make it special for clothing[13].

Home Textiles
It is used in bed linens, table covers, towels, bath robes, pillow covers.

Leisure Wear and Sportswear
Properties of modal make it ideal fabric for sport wear and leisure wear, because in both areas moisture management, comfort, air permeability is required which are considered the best properties of modal fiber.

Under Garments
It is used in under garments and lingerie due to its better fit and skin friendly properties.

10.4.3.2 Technical Applications
Tire Cords
Modal and viscose rayon due to high strength in natural material fiber were used in tire cord

Abrasive Ground Fabric
It is used in products of agriculture of technical purpose. Modal is having good wet modulus and biodegradable therefore it is preferred in agricultural technical applications.

Micro Modal
It is a trademark of Lenzing AG Company it is finest version of regular modal fiber. Due to micro structure, it has very goof moisture management properties and very soft. Used for lingerie and some extra softness required applications

Nonwoven Hygiene Products
Modal fiber is used in the nonwoven personal care products due to its extreme softness and moisture management property.
10.5 Cellulosic Regenerated fibers

Regenerated fibers are generated using cellulosic part of plant fiber. Then this part is dissolved into the chemical, after this it is used to manufacture this solution into the shape of resultant fiber. It is consisted of cellulose that includes cotton, jute and hemp this is the reason due to which it is called regenerated cellulose fiber. Major part of wood is consisted of cellulose.[20]

![](image)

Figure 43: Wood pulp and Bamboo tree

In composite field animal fibres have not been widely used while plant based fiber are mostly used. Regenerated cellulose fibres (RCF) lie between natural and manmade fibres and have used as composite reinforced. RCF’s primary constituent is cellulose that belongs to biomass origin.

10.5.1 Generations of Regenerated fibers

Rayon was the first generation of this cellulosic base fiber. In textile industry Rayon is also named as viscose rayon and artificial silk. It has brighter shines because the quality of lustre. Second generation: Modal is also the cellulosic base fiber that is famous for its soft surface. Third generation: Lyocell enrolled into this.[21]
Figure 44: Why regenerated cellulosic fibers are used

Modified Regenerated cellulosic fibers

Modified cellulose regenerated fiber have practically

- Tolerable tenacity
- Show excellent property in dye-attraction
- Anti-funguses property and
- Deodorizing nature[22]
- Excellent in safety without damaging the integral properties of the fiber.

10.5.2 Types of regenerated cellulosic fibers

Major numbers of regenerated cellulosic base fiber that are used in textile are,

- Acetate
- Viscose
- Lyocell
- Azlon
- Alginate fiber
- Seaweed fiber

10.5.3 Rayon

It is general term use for the family of regenerated fibers which produce the fabrics made of cellulose fibres by dissolving them in the different chemicals and spinning the resulted solution of viscous. Use of dissimilar chemicals and distinctions in procedures produce viscose (Rayon named is given in US), acetate, cuprammonium (cupra or cupro), lyocell, nitro silk and modal. as compare to other cellulosic fibers it is Mostly known by the production of bamboo. Artificial silk is previous word for rayon.
2nd main method of creating Rayon is using the wood pulp by making solution with mixing it with chemicals and this is the way to change them in the form of fibers. It is also called regenerated silk fiber because of its shiny surface, smooth texture and glossy effect. Other characteristics of Rayon fibers are smooth texture, unique gloss, moisture absorption, desorption (is a phenomenon whereby a substance is released from or through a surface) property and superior staining property. Rayon is shaped by the polymers that are exits in nature so this is the reason that it is neither synthetic nor a natural fiber. The term “viscose” is use for this reason. Cellulose base manufacture fiber was termed as rayon fiber and they also include acetate as well as viscose fiber.

In Europe, these fibers are generally termed as rayon fiber. It is first man made renovated cellulose fiber. Its shape is saw-like and round with smooth surface. When it gets wet it loses 30-50% of its strength. As this fiber is manufactured from polymers that that are natural therefore it is not an artificial fiber but it is a regenerated cellulose base fiber. Rayon is partially synthetic and termed as artificial fiber. The treatment with ammonia gas is good for a development of the soft feel of the blend of polyester/rayon fabrics.

![Micrograph of the Rayon fiber and cotton fiber (near fracture)](image)

**Figure 45: Micrograph of the Rayon fiber and cotton fiber (near fracture)**
Rayon is available in two value facts,

- Viscose rayon
- Cupra-ammonium rayon

As discussed before its name is viscose rayon and artificial silk, these terms are also used in textile industry. Rayon fibre a textile substance, made from cellulosic material, which can also be collected from the cotton linter and a soft fleshy tissue of tree called spruce.

![Spruce tree](image)

Figure 46: Spruce tree

Initially rayon was known as artificial silk due to having form of filament and it is also being like silk substance. Conversely, this resemblance not 100%. The reason behind the fact is the composition of chemical structure of rayon and silk fibers is totally different.

10.5.3.1 Mechanical Characteristics of Rayon

Rayon is a cellulosic base fibre so it’s mainly properties are like cotton or other natural cellulosic base fibers. Its moisture absorbency is greater than cotton.
### Properties of Rayon Fiber

<table>
<thead>
<tr>
<th>Property</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shape</td>
<td>Controlled by manufacturer</td>
</tr>
<tr>
<td>Diameter</td>
<td>It varies from 12 to 40 microns</td>
</tr>
<tr>
<td>Luster</td>
<td>vary from dull to bright</td>
</tr>
<tr>
<td>Strength</td>
<td>2.4 to 3.0 GPA</td>
</tr>
<tr>
<td>Elongation</td>
<td>19-24%</td>
</tr>
<tr>
<td>Elasticity</td>
<td>82 %</td>
</tr>
<tr>
<td>Density</td>
<td>1.5 for all types of Rayon</td>
</tr>
<tr>
<td>Moisture</td>
<td>(10.7 to 16) %</td>
</tr>
<tr>
<td>Dimension stability</td>
<td>Poor for all type of Rayon</td>
</tr>
<tr>
<td>Resistant to acids</td>
<td>Poor</td>
</tr>
<tr>
<td>Resistant to sunlight</td>
<td>Average</td>
</tr>
<tr>
<td>Insects</td>
<td>Rayon is a cellulosic base fiber so it cannot resist to silverfish and</td>
</tr>
<tr>
<td></td>
<td>termites attack but it has an affinity to resist to damage due to insect</td>
</tr>
<tr>
<td>To heat</td>
<td>Extend exposure will eventually degrade the fiber</td>
</tr>
<tr>
<td>Feel</td>
<td>Soft and comfortable for wearer</td>
</tr>
<tr>
<td>Drape ability</td>
<td>Good</td>
</tr>
<tr>
<td>Dye ability</td>
<td>easily dyed in wide ranges of color</td>
</tr>
<tr>
<td>Static charge</td>
<td>Unless the fabric is not made from short, low- twist yams it will neither</td>
</tr>
<tr>
<td></td>
<td>build up static charge nor will it pill</td>
</tr>
<tr>
<td>Insulation property</td>
<td>Bad insulation property so it is ideal for use in hot as well as in humid</td>
</tr>
<tr>
<td></td>
<td>environment</td>
</tr>
<tr>
<td>Abrasion resistant</td>
<td>Moderate</td>
</tr>
<tr>
<td>Dry strength</td>
<td>Moderate</td>
</tr>
<tr>
<td>Resilient property</td>
<td>This is not good like other cellulosic base fiber so it has bad wrinkle</td>
</tr>
<tr>
<td></td>
<td>property</td>
</tr>
<tr>
<td>Ironing temperature</td>
<td>It’s with stand property to ironing temperature is slightly less as</td>
</tr>
<tr>
<td></td>
<td>compare to cotton</td>
</tr>
</tbody>
</table>

Lyocell has brand name of Tencel by Lenzing. Advantages of Lyocell include,

- Chemical process of Lyocell is Environmental friendly
- Softness
- Good drape
- Resistance against bacteria that are the reason of producing scent

### 10.5.3.2 Basic Principles of Rayon Fiber Production

Developing process of rayon varies by the choice of using chemical and their consecutive influence on environment. The cellulose obtained from the tree is changed by chemical method in a soluble form. The solution is processed through spinneret for attaining a soft filament form which would be further converted in to final cellulosic regenerated fiber.
10.5.3.3 Viscose Rayon fiber
It was used in bulk production in the 1900s. In this procedure, the xanthate is obtained by joining of purified cellulose and then it is dissolved in dilute solution of caustic soda, after this it is extruded from the spinneret for getting filament form of fiber. By changing the drawing parameters in spinning process, the strength and stretching property of rayon may change.

It has largest market share because rayon is mostly used in apparel and home furnishing. Two names are used in market i.e. “Rayon” and “viscose.” Its low wet strength is its main property that makes rayon fiber popular from other fiber, this is the reason which makes it unstable and after wetting it may shrink or stretch. Dry cleaning is preferred for preserving the appearance of regular rayon base fabric. Its shrinkage is 10 % of its original shape after machine washing.

For specialized end used other sub types of Rayon are used. Their end use may be in one-use diapers, cleanliness, pads and medical goods because of having non-woven disposable markets and moisture-holding properties with high-absorption rayon fibers.

10.5.4 Acetate
In the manufacturing of acetate fiber, cellulose acetate is the fiber forming substance. Acetate is an obtained from cellulose by the following reaction.
It is prepared by reacting acetic acid, acetate anhydride and purified cellulose obtained from wood pulp in the presence of sulphuric acid.

10.5.4.1 History of Viscose Rayon
Modern chemistry initiated by the excited experimentation of first manufactured natural fibres. **Mid-19th century:** The first synthetic dyes were the result of the movement in the mid-19th century. Scientists exposed that cellulose could be dissolved in different solvents e.g. With combination of acetone or ether so this was initiative idea of creating a filament fibre having resemblances with silk from subsequent liquid.

**Mid 1850s:** Georges Audemars was the scientist who formed the 1st artificial silk fibres, by plunging spikes in the cellulosic solution comprised in solvent and then draw the needles from that solution for making thin or tinny fibres. His method was clearly unfeasible for bulk production and it took half century to produce a commercially worthwhile manufactured cellulosic fabric.

**1890s:** Method of Georges Audemars was named as nitrocellulose, used into production after more developments of another scientist Comte Hilaire de Chardonnay; it was based on filament that was development for light bulbs. This fabric has drawbacks of having high flammable nature, problems in aesthetic and process was costly to produce in comparison to acetate & cuprammonium.

**In the early 1900s:** Cellulose manufactured from various varieties of fabrics was at the headlines everywhere in the world. Articles had crazed about it in 1894. **1905s:** in this region viscose was sold in UK. **In 1906s:** world reached a field of fever with headlines “The Wonder of Cellulose” and stated, “Death of the Silkworm” and “Artificial Silk Can Be Made Cheaper than Rags.”
In 1910s: Viscose same into the market of US.

In 1911s: Viscose reached into New Zealand.

20th century: Regardless of these disadvantages, nitrocellulose is called “mother-in-law silk”. It was used to manufacture in the 1st decade of the 20th century, till the disturbances of World War I over its production.

Manufacturing steps

It is manufactured by natural resource that belongs to special kind wood; mostly spruce tree is used for extracting pulp.

Figure 48: Newspaper of early 1900s about viscose rayon

Figure 49: Manufacturing Process of Viscose Rayon
10.5.4.2 Manufacturing Process

Purification of Cellulose

In the first step of manufacturing of viscose rayon the purification of cellulose is done. Then barks are distant from its side and then cut into pieces that has dimension as follow,

\[ \text{7/8” x 1/2” x 1/4”}. \]

After treatment with the calcium bisulphite solution under pressure it is cooked with steam passed over it for about 14 hours. By this treatment the cellulose region of wood remains unaltered but non-cellulosic area called lignin is transformed into water soluble sulphonated compound. It is washed out with excess water to purify the remaining cellulose. After that its treatment with bleaching agent transformed them into a paper sheets called wood pulp.

Conditioning of Wood Pulp

To required dimension the pulp sheets are sliced through guillotine and are kept in a special room. By means of ventilators, air moves freely among the divisors to maintain the temperature of about 30°C. Through this way the desire amount of moisture can be maintained.

Steeping Process

The mercerizing or steeping is done by treating the conditioned wood pulp with caustic soda that transfers the high degree of polymerization cellulose (1000) into soda cellulose. In 1-14 hours, the sheet soaks maximum amount of soda and turn brown in colour. After that the excess amount of caustic soda is squeeze off under a pressure. 100 kg soda cellulose is obtained through 310 kg of soda.

Shredding or cutting process

Soda cellulose sheet that is soft and wet in condition is passed through shredding machine to cut it into small pieces. It takes about 2-3 hours to convert the sheet into fine crumbs.

Figure 50: Shredding and cutting process
Ageing Process

The fine crumbs of soda cellulose are kept in small galvanized drum for about 2 days at 28° C to get an ideal solution of cellulose. During this ageing process, in the presence of air the DP of cellulose is decreased from 1000 to 300.

![Ageing process diagram](image1)

**Figure 51: Ageing process:**

Churning Process or Xanthation

Crumbed soda cellulose after ageing are moved to hexagonal shaped, air tight, rotating chamber where 10 % carbon disulphide is added and churned together for 3 hours. The speed of rotating chamber is kept 2 revolutions per minutes. The colour of resultant product changes from white to the colour of orange reddish due to the formation of sodium cellulose xanthate.

![Churning process diagram](image2)

**Figure 52: Churning Process or Xanthation**
Mixing or dissolving Process

The small ball of sodium cell xanthate is formed in the result of xanthation process are processed to a mixer named discover that provided with a constant continuous agitator. During the process, a dilute solution of caustic soda is added at the same time and cooled it with 4-5 hours of continuous stirring. Colour of the solution turned into thick brown like honey. The resultant thick solution is called viscose and it contains 6.5 % NaOH and 7.5% cellulose.

Process of Ripening

To have best spinning properties viscose solution need to be ripened. Ripening is completed by stocking the viscose solution at 10-18°C for 4 to 5 days. The solution viscosity changes as it primarily decreases and later increased to its initial value. Then filtration of developed solution is done, the resultant product is ready for spinning function to manufacture viscose rayon filament.

Spinning Process

The viscose solution can pass from end to end spinnerets. The spinnerets have many holes dia 0.05-0.1mm. Filament extruded from spinneret directly face the solution containing H₂SO₄ (10%), soda sulphate (18%), ZnSO₄ 1 percent, Glucose 2 percent water 69 percent. 40-45°C temperature is provided in spinning solution.

Sodium sulphate precipitates the floating sodium cellulose xanthate. Sulphuric acid turns xanthate into cellulose, carbon disulphide and sodium sulphate. Softness and pliability is thought to be given by glucose to filament while strength is imparted by zinc sulphate.

Figure 53: Viscose rayon production process

The factors that affect properties of viscose rayon filament are,

- The structure and composition of spinning bath
- Coagulation speed
- Temperature of spinning bath
- Spinning speed
• Amount of stretch applied to filament during spinning
• Time interval of filament immersed in the spinning bath

Filaments coming out of the spinneret bath are guided to two rollers that lead them to the spindle for winding process. Brilliant gloss can be achieved due to its lustre property.

10.5.4.3 Properties of Viscose Rayon fiber:
• Rayon is very soft, cool comfortable and very good absorbent property but could not be able to protect body heat and used in humid steamy climatic conditions.
• Rayon fiber has the same comfort property as natural fibres.
• Rayon can easily be dyed in variety of colours.
• Rayon has very lower elastic recovery of any fibre.
• HWM rayon is very stronger and reveals good durability. HWM rayon can be machine washed.
• Usual rayon fibres recommended care for dry cleaning purpose only.
• Rayon can replicate the feel and texture of silk, cotton, linen and wool.
• Tensile strength of normal viscose rayon is 18-23 cN/Tex.
• Before going to break it normally it elongates 17-25% of its actual length.
• At 20% extension, it has elastic recovery of 60%
• It strength decrease at degree centigrade and decomposes at Degree centigrade.
• Specific gravity is 1.50
• It can withstand exposure to sunlight without discoloration.
• It has moisture regain of 13%
• It can be attacked by oxidizing agent like hydrogen peroxide.
• Hot dilute acid as well as cold concentrated acid can attack on it.
• It has high resistance to dilute alkali and can be attacked by strong alkalis.
• Resistance to insects is good but can be attacked by silver fish.
• Resistance to mildew is much better than cotton.

10.5.4.4 Applications of rayon
Rayon naturally has a prominent shine quality providing it an excellent lustre. Mostly, use of Rayon fibres in the industry of apparel, are in shirts, dresses, Jackets, women's Lingerie, scarves for girls, suits, ties for dress, hats and in the socks. Some categories of rayon fibres are used for substantial in upholstery, lighters of Zippo, bed sheets, window covers, furnishings as well as bedspreads, blankets and in the slipcovers. In industry, it is used as medical surgery items, in the non-woven stuff, tire cord, in the children's diapers, house use towels, Yarn: novelty yarns, embroidery, cord, and chenille.

Fabric: Crepe, lace, outerwear fabric and outwear, suiting, raincoat and as lining inside of the coats.

Apparel: mostly in the Dresses of women's, saris, jackets, linings, hats, sportswear, suit, ties, work cloth and Accessories.

Domestic textile: bed sheets, quilt covers, blankets and in the furnishing domestic items like draperies, curtain and as table covers.

Industrial textile: applications of the Rayon are also consisted in as reinforcement that is used to provide strength in the things of mechanical rubber.

Example: conveyer belts, tires and hoses and tapes of braided tapes
Diacetate Rayon

10.5.4.5 Production of Diacetate Rayon
Diacetate rayon is produced by treating the cellulose with acetic acid (acetic anhydride) having two acetate radicals thus called as the diacetate rayon. Most common form of diacetate rayon has 2 acetate groups for three hydroxyl groups. The ratio of these acetate groups has an impact on the solubility of the diacetate rayon. On the chemical reaction of acetic acid with cellulose flakes are produced which are dissolved in a solvent to produce spinning solution.

Schematic Diagram of the Production Process for Acetate Fiber

![Diagram of the production process for acetate fiber]

Figure 54: Production process of acetate fiber

The solution is passed through the small holes of 30-50 micro meter and after this the solvent is evaporated and the diacetate rayon is produced. The production of diacetate is carried through the dry spinning. The cross section of the diacetate is chrysanthemum.

Fiber Formation Process and Cross-Section of Acetate Fiber

![Diagram of fiber formation process and cross-section]

Figure 55: Cross sectional area of the Di acetate fiber

10.5.4.6 Characteristics of Di Acetate Rayon Fibers:
Cellulosic Nature

The cellulosic nature of the diacetate rayon makes it bio degradable and environmentally thus contributing towards a cleaner environment. This is now the biggest challenge faced by the world to make things biodegradable so that a certain thing diminishes from the environment without harming it. Despite its biodegradability cellulose diacetate has a wide range of applications. Here I am quoting the example of a patent in which the mixture of cellulose acetate, plasticizer and
starch was used to make a composite using the injection moulding. This patent gave a lot of freedom of to the manufacturing of the products making the production of biodegradable products easy with superior strength and mechanical properties.

Thermoplastic fiber

Thermoplastic properties of a fiber can be of a great use making it possible to be used in a lot of applications. One major application that I found due its thermoplastic nature was researched in 2003 for bio medical applications.

Absorption properties

The absorption properties of a material can at times be a curse for it and limits its use in the manufacturing of the different products. It was shown in the work done in 2004 that the cellulose acetate has good absorption and the products made with it deteriorate mechanically due to the moisture absorbed in it.

Bonding possibilities of di acetate rayon

It makes a good bond with the plasticizers. Thus, increasing its applications in the world of composites. Specially wherever there is a try to make biodegradable composite diacetate rayon is used and it can be used in many ways like in the form of fiber, in the form of film or even in the form of spherical granules.

High surface area

Diacetate rayon when used in the form of beads have a higher surface area and has its application in the biomedical field in the drug delivery.

Flame resistant

To make cheaper flame-resistant yarn the diacetate rayon is mixed with some of the basic flame retardant phosphorous compounds due to its good bonding with these compounds and helping in producing cheaper fire retardant materials.

Low U.V stability

Cellulose acetate gets deteriorated by UV light thus causing a great loss in its mechanical properties and the transmittance reduced due to the UV light absorbed and the chains are broken into shorter chains and end groups are added like hydroxyl groups. To make it more stable against light it is treated with nitrogen oxide by leaving the film in an evacuated chamber and left in the nitrogen dioxide foe two hours.

Dimensionally instable

It is hydrophilic in nature and due this problem its dimensions get changed and it gets easily swollen if the water in contact has the traces of chlorine in it.

10.5.4.7 Applications of Di Acetate Rayon

Magnetic Tape

Diacetate rayon replace metallic strips for being lighter in weight and easy to handle but later the diacetate rayon strips were replaced by the PET strips which were more dimensionally stable.
Fabric

Diacetate rayon came as revolution in the field of textile industry having a better feel and more absorptive nature. It is greatly used as a lining material due to its breathable nature. The lustrous nature of the fiber makes it a popular fiber to make the wedding dresses.

Filters

Diacetate cellulose is widely used as a cigarette filter as it is believed to block almost half of the tar present in the cigarette smoke but unable to block the carbon monoxide but still it is the most widely used as filters in the cigarettes.

Pen Nibs

Cellulose acetate is used now a day widely as pen nibs because of its high absorbency property.

Diapers

Diacetate rayon was widely used as an absorbent pad in the initial developments of the diapers because of its high absorbency but later it was replaced by the super absorbent polymers.

Kids’ toys

Lego one famous brand of kids’ toys were made of the cellulose acetate due to its good strength, good hand feels and good pleasant colours due to its good dye ability.

10.5.5 Triacetate Rayon

As obvious from its name this is type of cellulosic acetate having different characteristics from the normal acetate and diacetate. Due to difference in characteristics it has different applications which we will try to explore here. As we know that Tri means three so we can easily guess that this the cellulosic acetate having three acetate groups on each monomer of glucose. This is considered as a base for regenerated fibers. So, we can define Triacetate Cellulose as “Cellulosic acetate containing three acetate groups per each monomer of glucose”

Federal Trade Commission has defined it as “Type of cellulosic acetate having at least 92% of the acetylated hydroxyl groups”. During the process of synthesis of Triacetate, we try to acetylate cellulose completely while during the manufacturing of normal or diacetate cellulose id partially acetylated. To understand further about the structure and properties of triacetate we need to develop our better understanding of acetylation.

\[
\begin{align*}
\text{H}_3\text{C} & \quad \text{O} \\
\end{align*}
\]

Given above is the chemical structure of acetyl group. It has one Ethyl group connected to a carbonyl group through single bond. Carbonyl group has one free electron which helps in making its bond with the other R(alkyl) group. In the above structure second R(alkyl) group is shown with the zigzag line. So, “Introducing or adding an acetyl group into another alkyl group or any other compound is called acetylation”. Usually it takes place by the removal of hydrogen atom in the hydroxyl group making a typical type of ester linkage acetate.
10.5.5.1 Structure of Triacetate

If we look at the below structure of Cellulose we can see that their Hydroxyl groups attached to it and these are points where acetyl groups attached and replace the hydrogen making the cellulose Triacetate.
Changing Hydroxyl group with Acetyl has changed the properties of cellulose to a very large extent which we will study and try to compare with cellulose.

10.5.5.2 Manufacturing of Triacetate

Triacetate can be prepared from different origins of cellulose and there is long life research continued in this field where researchers are working on the acetylation of cellulose taken from different origins. Mr. Ahmed El Nemr*, Safaa Ragab, Amany El Sikaily, Azza Khaled are people who have worked in the synthesis of Triacetate from Cotton. Cotton has great attraction for researchers who are working on the field of structural and characteristic modification of cellulose as it is abundantly available in the nature. Secondly it has a higher DP value ranging from 2.5x10^5 to 1x10^6. Commercial production of acetates has been recorded since 1919 but these were majorly produced from wood pulp by treating it with acetic acid and acetic anhydride in the presence of sulphuric acid. In 1965, it was Schatzenberger who developed cellulose acetate for the first time by reacting cellulose with acetic anhydride in a closed/sealed tube at a temperature of 180°C.

They have done the process in which they have used cellulose with the DP value of approximately 460, and for its acetylation acetic-anhydride was used along with ethyl-alcohol and N-Iodosuccinimide. One gram of cotton for cellulose was taken in a flask along with 25ml acetic-anhydride and different quantities of NIS catalyst. Mixture was first heated to the boiling temperature and then condensed with the help of a condenser. As soon as the reaction got completed ethyl-alcohol and purified/distilled water were poured into the mixture. It was done just to breakdown the acetic-anhydride’s portion which didn’t participate in the reaction. Then it was distilled and dried in oven. In the same we can produce triacetate at large scale just by adding the quantities of all chemicals and providing them more time for complete reactions.

We can check the Degree of substitution of the product using FT IR Spectrometer and Raman Spectrometer. It was observed that using different quantities of catalyst and providing different reaction times gave different values of yield and DS of product. Below is the detail of chemical reaction took place
Other Research is also being carried on the cheaper acetylation of the cellulose because there is a need of catalyst to break down the intermolecular bond in cellulose while energy obtained by the collaboration of cellulose and acetic anhydride is not high enough to breakdown the bonds of cellulose. So, catalyst helps in this regard. It means this reaction is very slow without a catalyst and this brings the attraction of scientists in this field. A lot of work has been done to introduce the cheaper solid catalysts like zinc-chloride for the esterification process of cellulose. Ahmed El Nemr and his co-workers have worked on the use of ZnCl\textsubscript{2} for the esterification of cellulose extracted from cotton on a commercial scale. They have done the process under microwave irradiation. They observed that irradiation conditions had a good impact on the yield of acetate in a reduced time with a maximum yield of 95.83%. This team has claimed that Zinc chloride is not only effective but also cheaper and less toxic for this purpose.

On the industrial scale triacetate is conventionally produced from the wood pulp. It can be done in both batch and continuous process. Below we will discuss continuous process it has many advantages and some disadvantages as well. This process is a patent technology and has the following steps,
Prepare Suspension

Here in this step we make the batch by dispersing the charge in conventional apparatus known as hydrapulper. This process can be done in any one of the water or aqueous acid. After the batch preparation, it is stored in a tank from where it is supplied to the next process.

Acetylation

Now the water or aqueous acid present in the suspension prepared in previous step is replaced by the pure acetic acid. This process is being done on a belt type of filter which is multistage. This filter is called “displacement filter”.

So, in order to start the acetylation displacement is done. Where suspension is passed through filter in order to remove water completely then cellulose is pressed and shredded. Each step is performed in vacuum. Then it is further fed into the acetylation kneader where reaction of acetylation is done in the same as we explained above.

Hydrolysis

This process is performed in the availability of water in a vat. These Vats has the ability that it can be cooled or heated. After this process of hydrolysis syrup is precipitated further.

Maturing & Washing

After the precipitation of syrup, it is fed into a drum which has rotary function for ripening. It is then further moved to washing filters, these two processes are done in continuous just like whole production process

Drying & pressing

Then at the end Triacetate is passed through a press where its draining occurs. From here it is further moved to dryer and then with pneumatic phenomenon it is passed into tanks for storage.

10.5.5.3 Characteristics OF Triacetate

Triacetate has some better properties as compared to normal acetate due to complete acetylation of the chain. As mentioned above about 95% of the hydroxyl groups are acetylated during manufacturing of triacetate. Due to this it has following properties

Resistance to Heat

Triacetate has a very tremendous property of its better heat resistance as compared to the normal acetate. Therefore, it can be washed easily at higher temperature. Temperature in laundry is important factor if we consider cost. In Europe, most expensive factor is worker if we raise the temperature then we can get better production with the same number of employees.

Resistance to Alkali

Along with the better heat resistance property it has good resistance to alkali, which again makes it suitable for the laundry washing as mostly chemicals involved in the laundry washing are alkaline based.

Better Drying property

Just like better heat resistance it has good drying ability. This makes it energy efficient product as it has lower moisture regain. It is also a disadvantage at the same time because it can cause over drying of the product when mixed with others.
Low Swelling

As we know that fibers shrink due to swelling after the absorption of moisture. But Triacetate has low moisture regain due to which it has very shrinkage. This makes it more suitable in the textiles where dimensional stability is required.

Resistance to Wrinkle

Today there is a big demand for the wrinkle free textiles. There is a lot of work going on in the field of chemical finishes where different finishes are applied to get make the fabric wrinkle free. Triacetate has better yield strength due to which it has good elastic properties. This makes this fibre resistant to de-shape permanently and crease formation. Wrinkle resistance of this fibre makes it suitable to such products.

Aesthetics

Due to the modified surface of cellulose it has very appealing drape in the products. This property of triacetate is much better than other synthetic and man-made fibres.

Micro level properties

It has number average molecular weight of 30,000 to 350,000 g/mole. While average molecular weight is 14,000 to 408,000 g/mole. It has polydispersity index of 3.2 apx while degree of polymerisation is up to 1670. But it depends on the raw material we select for the synthesis of the Triacetate. It has a tenacity of 2.5g/d while moisture regain is 6.5%.

Resistant to Hydrocarbon

In the form of film, it is resistant to most of the hydrocarbons, Oils grease and many solvents. It also has the glossy surface on the film level.

10.5.5.4 Applications of Triacetate

“American review Textile Organon” is the organisation which gives the position/consumption of Triacetate every year. According to this organisation production of Triacetate increased by 100% from 1955 to 1965. They have included all the textiles like tow, fibre and yarn. Other than that Triacetate has huge demand in the film and membrane making industry

Filmography

Triacetate has a good consumption in the LCD and polarized fil making industry. It is in use of making photographic films from early 70s. It is more reliable and supportive for this mechanism than normal acetate but there is a continuous research going on to use it in the replacement of fully synthetic materials in this industry.

Membranes

Today the biggest research on the Triacetate is being conducted on its application in the membrane forming material. This application is extending day by day. Xiao Wang and his Team has developed the high water permeable membrane. This has improved anti-biofueling and mechanical properties for the forward osmosis process. Below is the diagram of the function of the membrane. These membranes are used in different applications like waste water treatment and in the fertiliser industry.

Transistors

It also has an application in the field of electronics. It is used to produce organic based thin film transistors. Due to its hydrophobic properties, it is considered best in this application.
Fibres and Yarns

Due to its glossy and polished surface Triacetate has a huge application in the yarns where shining surface is major requirement of the end product. Its shine is comparable to silk. Due to this property Triacetate is gaining its fame in the fashion industry.

Fabrics

As described above that cellulose Triacetate has far better performance when we consider characteristics like moisture management. Due to its low moisture regain it is easy to dry and that’s why it has good application in the laundry business. Right from the home textiles industry to Fashion industry everyone knows and fully utilising the Triacetate. It is also used in Sportswear after blending it with Nylon and other fibres.
11. Synthetic fibers

11.1 Polyester
Polyester is made of two words “Poly” and “ester”. Poly means many and ester is an inorganic compound. Polyester is a manmade fiber. It is 2nd widely use fiber after the cotton. It is prepared by the condensation reaction. It has ester group linkage. Polyester is accidently produce during the formation struggle of Nylon by Du Pont. Polyethylene terephthalate is important polyester among all synthetic fiber. There are many companies which are making polyester like ICI, Du Pont, CAFI, Hoechst etc.

11.1.1 Types of Polyester
There are different types of polyester available,

- Polyethylene terephthalate (PET)
- Poly-1, 4-cyclohexylene-dimethylene terephthalate (PCDT)
- Melt-spun wholly Aromatic polyester
- Flame retardant polyester
- Antistatic Polyester
- Spinning without spinnerets polyester
- Basic dyeable polyester
- Coloured polyester
- Biodegradable polyester

Some polyester types which discuss above are patents.

Polyethylene terephthalate (PET), PET polyester is produce in monofilament, multifilament and staple fibers yarns.

11.1.2 Raw material and production process
PET is made by the condensation polymerization of terephthalic acid or dimethyl terephthalate with ethylene glycol. The ethylene glycol is obtained by the oxidation of ethylene. Para-xylene is oxidized with nitric acid or in air to obtain terephthalic acid.
In condensation process methyl alcohol is eliminated and ester linkage produced in monomers. The condensation polymerization process is carried out in the presence of heat. The obtained colourless polyester, after a desired degree of polymerization, is cooled and fed into the cutter to cut it into small chips form.

These chips send for spinning through suction pipe. In spinning section, the chips are dried to remove moisture then PET chips melts at 250°C in hopper and then pump through the spinneret. The filament polyester produced by this process is then dried and packed. This undrawn yarn is stretch at high temperature to increase its tenacity. The staple fibers are produced by passing high no of filaments together from crimper to produce the crimp. Then these are cut into staple fibers.

11.1.3 Properties of Polyester fiber

In order to describe PET properties, it is divided into two groups,

- Filament yarn
- Staple fibers

The properties PET which are discussing here is produced by ICI and have trade name “Terylene”. These fibers are smooth and have circular cross-section but some types have Trilobal cross-section.

11.1.3.1 Physical Properties

Tenacity

<table>
<thead>
<tr>
<th>Property</th>
<th>Filament</th>
<th>Staple</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tenacity</td>
<td>70.6-35.3</td>
<td>57.4-22.1</td>
</tr>
<tr>
<td>cN/Tex</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Elongation

<table>
<thead>
<tr>
<th>Property</th>
<th>Filament</th>
<th>Staple</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elongation</td>
<td>30-8</td>
<td>50-20</td>
</tr>
<tr>
<td>%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Elastic recovery

These have good elastic recovery when they stretch, bend or compress.

Modulus

They have high resistance to deformation so they have high modulus.

<table>
<thead>
<tr>
<th>Property</th>
<th>Filament</th>
<th>Staple</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulus</td>
<td>1148-883</td>
<td>706-265</td>
</tr>
<tr>
<td>cN/Tex</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Abrasive Resistance

The abrasion resistance of PET as compare to other textile materials (including natural and man-made) are good.

Creep

They have high modulus so they have good creep characteristics.

Specific Gravity

Its specific gravity is 1.38 g/cm3

Effect of Moisture

It absorbs a very small amount of moisture. Its moisture regain is 0.4% in 65% R.H and at 200°C. The moisture have no effect on its tenacity and elongation.

Thermal Properties

Its softening temperature is 260°C. It lost colour after one month when it is treated with air at 1500°C.

Shrinkage Properties

The filament yarn shows 10% shrinkage in air at 1500°C. High tenacity yarn show high degree of shrinkage as compare to medium tenacity yarn. In boiling water, it shows high higher shrinkage as compare to hot air. The staple fibers have less shrinkage as compare to filament yarn.

Effect of Sun light

It has high resistance to sunlight. After a long time, it lost a very small amount of strength but don't lost colour.

11.1.3.2 Chemical properties

Oxidizing and reducing agents

It has good resistance to oxidizing and reducing agents. They have ability to withstand with bleaching agents.

Acids

Due to ester linkage, the hydrolysis is done. But the rate of acid hydrolysis in polyester is slow. Due to this reason, it has good resistance to mineral and organic acids.

Alkalis

Its resistance to alkali is not good. It shows poor resistance towards hot and concentrated alkalis but have good resistance to dilute alkalis.

Organic solvents

Terylene has good resistance towards organic solvents like acetone, ether, methyl alcohol, ethyl alcohol etc. At room temperature, they don't have a significant effect on its strength. Its resistance towards hydrocarbon oils is also excellent.
Insects and microorganisms
The insects like sliver fish, larvae, ants and pests don’t attack on it. Similarly, it has good resistance to fungi and bacteria but some types of bacteria have ability to attach.

Allergenic properties
It is inert and don’t produce any problem on skin.

Electrical properties
It has very low moisture regain so its insolation property is good.

11.1.4 PCDT
Poly-1, 4-cyclohexylene-dimethylene terephthalate

It is produce in 1958 and its trade name is Kodal.

11.1.4.1 Raw material and production process
They are made by the condensation polymerization of terephthalic acid and 1, 4-cyclohexane dimethanol. Terephthalic acid is gain from para-xylene. Mixture of two isomers is used to produce 1, 4-cyclohexane dimethanol. Both reactants are mixed and heated at 2000C in the presence of catalyst. During the process methyl alcohol is eliminated. The temperature is gradually increases until the desire polymer is not achieved.

The polymer produces by this method have 2900C melting temperature. The molten polymer is then passed through spinneret and drawn 4 to 5 time to its original length at 1200C.

They are normally produced in the form of staple and available with respect to different counts and lengths range.

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11.1.4.2 Properties
PCDT has smooth surface and round cross-section and has very good physical and chemical properties.

11.1.4.2.1 Physical Properties of PCDT

Table 12: Physical properties of PCDT

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Property</th>
<th>Units</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tenacity</td>
<td>cN/Tex</td>
<td>22-26.5</td>
</tr>
<tr>
<td>2</td>
<td>Elongation</td>
<td>%</td>
<td>24-34</td>
</tr>
<tr>
<td>3</td>
<td>Elastic property</td>
<td>cN/Tex</td>
<td>265</td>
</tr>
<tr>
<td>4</td>
<td>Avg. stiffness</td>
<td>cN/Tex</td>
<td>97</td>
</tr>
<tr>
<td>5</td>
<td>Avg. toughness</td>
<td>g/cm</td>
<td>0.5</td>
</tr>
<tr>
<td>6</td>
<td>Specific gravity</td>
<td>g/cm³</td>
<td>1.23</td>
</tr>
<tr>
<td>7</td>
<td>Moisture regain</td>
<td>%</td>
<td>0.4</td>
</tr>
<tr>
<td>8</td>
<td>Melting point</td>
<td>0°C</td>
<td>290</td>
</tr>
</tbody>
</table>

11.1.4.2.2 Chemical Properties
- It has very good chemical properties as compare to PET polyester. Its resistance towards alkalis and acid is better than PET polyester.
- They have resistance to organic solvents. But they swell deform in phenol and acetone.
- Its behaviour towards insects and microorganisms is same as PET polyester.

11.1.5 Melt-spun wholly Aromatic polyester
It is the fully aromatic polyester while the other polyesters are partially aromatic. It is produce by the polymerization of p-hydroxybenzoic acid and 6-hydroxy-2-naphthoic. It was produced to use in tyre cord instead of para-aramids but due to its high cost it is used in electronic parts.

Its fiber and filament manufacturing process is similar the conventional polyester. Melt spinning technique is used for its spinning.

11.1.5.1 Physical and chemical properties
Vectran have very excellent physical and chemical properties.
- It has high strength and modulus as compare to conventional polyesters
- Its creep and abrasion resistance are very high
- It has good flex/fold characteristics
- Its moisture absorption is very low
- Its resistance towards chemical is very high
- Excellent cut and impact resistance
- Very high vibration damping characteristics

11.1.6 Flame retardant polyester
It is manufactured by heating the mixture of terephthalic acid and ethylene glycol at 280 °C for 90 min in the presence of Sb₂O₃ and cobaltous acetate. After that polymerization is done in the presence of phenyl dihydrogen phosphonate and flame retardant polyester is obtain. The flame-retardant polyester is also obtained by doing the condensation of TPA and ethylene glycol in the presence of B₂O₃ and magnesium acetate.

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11.1.7 Antistatic Polyester
Antistatic polyester has better handle properties from regular polyester. It is prepared by polymerization of DMT and ethylene glycol. The reactant esterification is done in the presence of zinc acetate dihydrate and polycondensed in the presence of titanium dioxide. Then the polyester is spun at 290 °C.

11.1.8 Spinning without spinnerets polyester
Normally polyester is spun by passing it through spinnerets in molten form. The USA Company designs a machine in which polyester is spun without spinnerets. Here the molten polymer from extruder is moved upward from bottom to top of the heated container. On the top winding arrangements wind the monofilaments.

11.1.9 Basic dyeable polyester
The basic dyeable polyester gives much deeper shade when it is dye with basic dye as compare to conventional polyester fiber. DMT and ethylene glycol are used as a main component of its manufacturing. Calcium hydroxide is added in it and heated it above 155 °C for 2 hours then mixed with sodium benzene, 1,3-disulphonate, antimony trioxide and phosphoric acid and heated at 285 °C. The obtained polyester spinning is done at 295 °C.

11.1.10 Coloured polyester
The polyester with built-in dyestuffs was prepared in 1968 by Borodkin. In this method dyes were added during the polymerization process. But the problem was that their tensile strength, elongation at break and dye colour become faded when dyes were added start or end of polycondensation.

Later, Russian done it by another method. They first manufactured the esterification product (of dimethyl terephthalate and ethylene glycol) in the presence of disperse dye. The regular polyester was also manufactured. Then they mixed both (color and colourless) by melting it and spun it by passing through spinnerets in the color polyester.

11.1.11 Biodegradable polyester
The biodegradable polyester was first developed in 20th century but due to its easy to hydrolysis it was not useful in textile. In 1960, it realized that due to this property (easy to hydrolysis) they can be used in medical field. There are different types of biodegradable polyester.

- Polyglycolide
- Polylactide
- Polycaprolactone
- Polydioxanone
- Polytrimethylene carbonate

11.1.11.1 Properties
The properties of biodegradable polyesters are given as follows,

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Polymer name</th>
<th>Melting Temp C0</th>
<th>Modulus GPa</th>
<th>Degradation (In months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Polyglycolide</td>
<td>225-230</td>
<td>7.0</td>
<td>6-12</td>
</tr>
<tr>
<td>2</td>
<td>Polylactide</td>
<td>173-178</td>
<td>2.7</td>
<td>Above 24</td>
</tr>
<tr>
<td>3</td>
<td>Polycaprolactone</td>
<td>58-63</td>
<td>0.9</td>
<td>Above 24</td>
</tr>
<tr>
<td>4</td>
<td>Polydioxanone</td>
<td>depolymerizes</td>
<td>1.5</td>
<td>6-24</td>
</tr>
</tbody>
</table>

11.1.11.2 Degradation Mechanism
Basically, two types of mechanism occur in the biodegradable polyester, bulk erosion and surface erosion. Both have different effects on strength loss. Here two processes take place one is the rate of diffusion of water in material and other is chain-breaking reaction. If the rate of hydrolysis
is faster than rate of water diffusion, then surface erosion take place. If the rate of chain-breaking is lower than diffusion than bulk erosion occurs. Mostly polyester degradation occurs due to bulk erosion. As they are semi crystalline so hydrolytic attack first occurs on amorphous portion and then crystalline regions.

11.1.12 Applications

Apparel
Polyester is most widely used fiber after the cotton in the manufacturing of yarn, fabric and apparels.

Curtains
Due to its excellent sunlight resistance, it is used in curtains behind glass.

Floor Coverings
It is also widely using in floor covering, especially in sliver knit rugs and tufted carpeting.

Laundry Equipment
Due to its good strength, excellent heat and abrasion resistance it is used in bags packing flannel, laundry blankets and laundry bags.

Fire hose
Polyester has high strength and high modulus, so they are used in the production of fire hoses.

Ropes and nets
As polyester have good strength, sunlight resistance and chemical properties. Due to this reason, they are widely used in the manufacturing of ropes and nets.

Filling
Due to its light weight and low moisture regain, polyester fibers use in the filling of pillow and quilts. The other important factor is that they are easy to wash and dry.

Thread
They are used in sewing thread due to its high strength and modulus.

Paper making
Polyester is widely use in the paper making field due to its less moisture regain and resistance to sunlight and chemicals.

Insulation
It has electrical insulation property. So, its fabric is used as insulating material in motors and other electrical devices.

Tyre
Polyester is also used in tyre cords.
11.2 Polyamides
That polymer which contain a major part of amide linkage in the main chain is known as polyamide. In natural form polyamide are following,

- Silk
- Wool

While in synthetic form polyamide are following,

- Nylon
- Types of Nylon such as 6 and 6.6

Basically, synthetic nylon is done by condensation polymerization. Spun of nylon in two different structure are following:

- \( \text{H}_2\text{NRNH(COR\text{CONHRNH})}_n\text{COR\text{COOH}} \)
- \( \text{H}_2\text{NRCO(NHRCO)}_n\text{NHRCOOH} \)

In this structural formula of Nylon R & R (prim) and n shows that R & R: Aliphatic groups can be used to represent the chain other than functional group. n: Number of repeating units. Hexamethylene and Adipic acid reaction done to formation of structure name Polyhexamethylene Adipamide (A) and it is known as Nylon 6.6. While self-condensation of Caprolactam is cause formation of Nylon 6.

11.2.1 Nylon 6,6
It is synthesized by polycondensation of hexamethylene diamine and adipic acid. Equivalent amounts of hexamethylene diamine and adipic acid are combined with water in a reactor. This is crystallized to make nylon salt, which has precisely stoichiometric equivalents. The nylon salt goes into a reaction vessel where polymerization process takes place either in batches or continuously.

\[
n \text{HOOC-(CH}_2\text{)}_6\text{COOH} + n \text{H}_2\text{N-(CH}_2\text{)}_6\text{-NH}_2 \rightarrow [-\text{OC-(CH}_2\text{)}_6\text{-CO-NH-(CH}_2\text{)}_6\text{-NH}_2\text{-]}_n + 2n \text{H}_2\text{O}
\]

Removing water drives the reaction toward polymerization through the formation of amide bonds from the acid and amine functions. Thus, molten nylon 66 is formed. It can either be extruded and granulated at this point or directly spun into fibers by extrusion through a spinneret (a small metal plate with fine holes) and cooling to form filaments.

11.2.1.1 Raw Material and Production
Different steps are included in the production of nylon 6.6 are involved and the flow chart is:
Reactant Synthesis

As described above it is formation of condensation of two substance hexamethylene diamine and adipic acid. First step reaction synthesis of production also contains different routes to complete it which is following.

**Cyclohexanol Route**

1. Cyclohexanol formation is done by Reduction of Phenol by hydrogenation with the help of catalyst.
2. Benzene turn into cyclohexane before turn into cyclohexene.
3. After formation of cyclohexene reaction of oxidizing in air occur and forming a mixture of cyclohexanol and cyclohexanone.
4. This mixture converts into Adipic acid by oxidizing.
5. Adipic acid is reacted with ammonia to form adipamide.
6. Formation of adiponitrile is done by dehydrated of Adipic acid.
7. Reduction of Adiponitrile is hexamethylene diamine.

In this picture, every step number explain how synthesis reaction take place into cyclohexanol route.
Butadiene Route

In this picture, every step number explain how synthesis reaction take place into butadiene route.

- Dichlorobutane is the product of butadiene is reaction with chlorine gas.
- Formation of 1,4 dicyanobutene is done by treated of hydrocyanic with dichlorobutane.
- Formation of adiponitrile is done by hydrogenated by dicyanobutene.
- Hydrolysis of adiponitrile cause product of Adipic acid.

Furfural Route

In this picture, every step number explain how synthesis reaction take place into furfural route.

- Furfural conversation into furan and then tetrahydrofuran by reduction.
- And then tetrahydrofuran by reduction.
- Formation of 1,4 dichlorobutane by the treatment of HCL with tetrahydrofuran.
- Finally, resultant product adiponitrile is get process of sodium cyanide with 1,4dichlorobutane.

11.2.1.2 Polymerization
Polymerization flowchart for Nylon 6.6 is as following,
For the process of polymerization one thing is must be important specially for poly condensation polymer and that thing is degree of polymerization which can be low, medium, high so it can be processed further in process without problem.

For this purpose, to attain the high degree of polymerization two ways can be used.

1. Components used for it must be balance and adequately controlled.
2. Calculated the non-stoichiometry proportion of components carefully.

Stabilization

Stabilization is the process of calculate the molecular weight at which level is required. The amount of that reactant which is calculated. And calculate value of reactant shows at which level block the polymer chain after reaching desired average molecular weight.

If molecular weight is low then solution is not able to spin its flow like water due to very low density. If molecular weight is high then it is also not able to spin because of high entailment of chains and high density. So, at the end molecular weight must be average which easily spun in next process. For the manufacturing of Nylon 6.6 molecular weight must be between approximately 12,000 to 22,000 to spin the polymer into fiber form.

Polycondensation

Reactants hexamethylene and adipic acid used for it must be full fill the conditions of polymer and stabilization to spun into Nylon fiber and for this purpose a salt hexamethylene diammonium adipate known as nylon salt is used. Some conditions for condensation are as following,

- Temp: 220-230°C
- Time: 2 hours
- Pressure: 17.5 Kg/cm² or 250 lb/in

After giving the temp, it gradually increases of molten material to attain the desired degree of polymerization then solidify it by cooling it with water. Collect this polymer having ribbon like shape with specs 30cm (1.2 in) wide and 6mm (1/4 in) thick.

11.2.1.3 Spinning

Melt spinning technique is used to produce the Nylon fiber. Polymer melt until convert into molten material then pass it through spinnneret. At the ejection point stream of cooled air is passed to solidify it forming because of solid filament.
11.2.1.4 Drawing
Drawing is the name of attenuation means increase in length and reduction in weight. This phenomenon carried out help of fiber or filament to increase its strength. Effect of drawing at appearance is make it translucent and lustrous. To enhance the strength and luster of polymer along fiber axis because after spinning it is weak and not enough long to stable. For this purpose, use ¾ drawing. According to the mechanism or principle of drawing the speed of front roller is faster than the back roller. Similarly drawn process use here as used in the production of rayon follow the principle of drawing and the speed of front roller is four to five times more than speed of back roller.

Before the winding of drawn fiber heat set treatment done by passing it through the boiling water. And suddenly wind align filament at package. So, it is the overall process of the production of Nylon 6.6 start from Reactant synthesis to Drawing till winding. It further can be processed but it is not the part of production of Nylon 6.6. It just the treatments to improve properties.

11.2.1.5 Physical Properties
Tenacity
Nylon has the tenacity about 40.6-51.2 cN/tex.

Elongation
According to the categories of the filament it has different elongation ranges such as regular, high tenacity and staple filament has the elongation about 25-33, 18-25, 38-41 per cent respectively.

Tensile Strength
Just like in elongation case ties of filament having different tensile strengths such as regular, high tenacity and staple filament has the tensile strength about 4440-5450, 6401-9099, 4199-4520 Kg/cm² respectively.
Modulus
350-529.2cN/tex

Stiffness
158.99 cN/tex of regular filament widely used in industry.

Toughness
1.0775 of regular filament widely used in industry.

Abrasion Resistance
Very Good resistance in case of fire and abrasion.

Specific gravity
It has the range about 1.133.

Moisture Regain
It has moisture regain about 3.99-4.445 %.

Melting point
Above the 50°C nylon is going to be melt.

11.2.1.6 Applications
Nylon 6.6 can be used in multidiscipline according to the requirement in end use relative to its properties.

Carpets
Due to its very good abrasion resistance and appearance. It is widely used in carpets. Varieties of nylon fiber used in carpets are Frieze and Nubby, Velvet and Bulk Continuous Filament.

Upholstery
Due to good strength nylon is applicable in upholstery items.

Hosiery
Due to the properties such as no wrinkles, elastic memory and recovery and good appearance it is going to be use in hosiery items from the day enter in market to compete with regular used fiber.

Gloves
Ladies gloves to be made from it to use in laundry due to its chemical resistance to avoid or safe the skin from any damage.

Outwear
Due to unique appearance, it is used in jackets and other hoodies in laminated and lining forms to get the aesthetic beauty of the fabric.
Tyre Cord

High RKM, very good abrasion resistance and fatigue resistance it is used in tyre cord to increase the efficacy of tyre rather then he other fiber previously used before the entrance of Nylon in the market.

Conveyor belt

It is one of the most used application of it in industry because of its high strength, high impact modulus etc.

11.2.2 Nylon 6

Reactant polycaproamide used manufacturing by self-condensation technique,

\[ \text{CH}_2\text{(CH}_2\text{)}_4\text{CONH} \rightarrow \text{NH(\text{CH}_2\text{)}_5\text{CONH(\text{CH}_2\text{)}_5\text{CONH(\text{CH}_2\text{)}_5}}} \]

11.2.2.1 Types of Nylon

The types of nylon are as following,

- Multifilament yarn
- Monofilaments
- Staple and tow

Appearance

- Bright
- Semi dull
- Dull
- Optical bleach after treatment

Classes

- Regular tenacity
- High tenacity

11.2.2.2 Production

The steps of production are followings,

\[ \text{REACTANT SYNTHESIS} \rightarrow \text{POLYMERIZATION} \rightarrow \text{SPINNING} \]

Reactants synthesis

The steps used for reactant synthesis of caprolactam used to produce Nylon 6 are as following,

- Cyclohexanone Route
- Cyclohexane Route
- Cyclohexylamine Route
- Hex hydro benzoic acid

Cyclohexanone Route

The principle used to produce caprolactam from this technique is very easy. First method is get chlorobenzene to treat the benzene with chlorine and after conversion of it is in phenol done process of reduction and oxidation to get the cyclohexanol and cyclohexanone respectively.

Second method is get nitrobenzene to treat the benzene with mitogen and after conversion of it is in aniline done process of oxidation to get the cyclohexanone. Third method is to get cyclohexane to treat the benzene with hydrogen after it done process of oxidation to get cyclohexanone.
Cyclohexane Route

The following equation explain the reaction,

\[ \text{Benzene} + \text{hydrogen} \rightarrow \text{Cyclohexane} \]

\[ \text{Cyclohexane} + \text{Nitro Compounds} \rightarrow \text{Cyclohexanone oxime} \]

Cyclohexamine Route

\[ \text{Aniline} + \text{Hydrogen} \rightarrow \text{Cyclohexanone amine} \]

\[ \text{Cyclohexanone amine} + \text{hydrogen per oxide} \rightarrow \text{Cyclohexanone oxime} \]

Hexahydrobenzoic Acid Route

\[ \text{Toluene} + \text{oxidizing agent} \rightarrow \text{Benzoic Acid} \]

\[ \text{Benzoic acid} + \text{Hydrogen} \rightarrow \text{Hexahydrobenzoic Acid} \]

\[ \text{Hexahydrobenzoic Acid} + \text{Nitrosyl Sulphuric} \rightarrow \text{Caprolactam} \]

11.2.2.3 Polymerization

Polymerization to convert the caprolactam into Nylon is done by two steps,

- Non-Aqueous Process
- Aqueous Process

In Reaction types are as following,

- Polycondensation
- Polyaddition reaction

Non-Aqueous Treatment / Process

Polymer form from the caprolactam can be achieved by heating it about 280\(^\circ\) C temperature to open the rings of it. Range of degree of polymerization is about 200. Form this method final product Nylon has better physical properties than other properties like mechanical.

Polycondensation Reaction

This process is defined as start of the Nylon 6.

Polyaddition Reaction

In this reaction first open the ring of raw material then link it to make a straight or aliphatic chain. It has degree of polymerization about 120-140. From the molten stage after given temperature about 85\(^\circ\)C it can be spun to get the Nylon.

11.2.2.4 Spinning

Melt spinning is required to process the nylon about 215-217\(^\circ\) C. The polymer of Nylon can withstand about 250\(^\circ\) for 3/4 to full day so direct spinning can be done at it. Spinning of nylon can be processed at two stages,

- Polymer chips
- At the time of polymerization
Uniformity is a basic factor need at the requirement of multifilament while in case of staple has not important. Spinning of polymer chips having pure chains of Nylon is done while the excess nylon in polymer chips is removed with the help of water.

11.2.2.5 Drawing
The principle of attenuation is, speed of next roller is more than previous. Same principle is used for the drawing of Nylon. The speed of front roller is 4 times more than the first roller having drafting system of 2/2. Conditions used for drawing:

- Temperature: 150
- Relative humidity: 55-65%

11.2.2.6 Twisting
Requirement of impart twist can be fulfilled by old mechanism and it can be calculated according to end use such as,

- TPI for Hosiery Yarn 32
- TPI for Weaving Yarn 6-8

11.2.2.7 Washing and Twist Setting
To remove the excess caprolactam at filament stage of Nylon use hot water after spinning and it also helps to set the twist.

11.2.2.8 Coning
After drying application of size is applied at the stage of winding to make it stable.

11.2.2.9 Structure and Properties
Characteristics of Nylon 6 are as following,

- Smooth Surface
- Featureless like Glass
- Cross section has Round

11.2.2.10 Physical Properties
Tenacity
Just like nylon 6.6 it is different tenacity for different categories

<table>
<thead>
<tr>
<th>Type</th>
<th>Tenacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>40-52 cN/tex</td>
</tr>
<tr>
<td>Staple</td>
<td>63-74 cN/tex</td>
</tr>
<tr>
<td>High Tenacity</td>
<td>34-49 cN/tex</td>
</tr>
</tbody>
</table>

Tensile Strength

<table>
<thead>
<tr>
<th>Type</th>
<th>Tensile Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>5200-5900 Kg/cm²</td>
</tr>
<tr>
<td>High Tenacity</td>
<td>7800-8500 Kg/cm²</td>
</tr>
</tbody>
</table>

Elongation

<table>
<thead>
<tr>
<th>Type</th>
<th>Elongation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>22-44 %</td>
</tr>
<tr>
<td>Staple</td>
<td>15-20 %</td>
</tr>
<tr>
<td>High Tenacity</td>
<td>24-49 %</td>
</tr>
</tbody>
</table>

Initial Modulus
It has low in the range of 310-442 cN/tex for regular filament.

Stiffness

For regular and HT filament has the range of stiffness about 204 & 389 cN/tex respectively.

Toughness

Similarly, for regular and HT filament has the range of toughness about 0.669 & 0.679.

Abrasion Resistance

The abrasion resistance of Nylon 6 is very high.

Thermal properties

As define earlier having melting point about 215°C.

Moisture Management

It has moisture regain about 3.99-4.99 %.

Effect of Age

Very good property. It can be defined as negligible.

Elastic behaviour

Recovery: 5.99-7.99 %

11.2.2.11 Chemicals Properties

Two types of effect cause due to chemicals such as,

- Non-permanent effect
- Permanent effect

Non-Permanent effect of chemicals

Alcohol, ethers, ketones, alkalis, aromatic hydrocarbons, soaps, aliphat hydrocarbons and detergents compounds have the non-permanent effect on Nylon 6.

Permanent effect of chemicals

Basically, oxalic materials have permanent effect at Nylon 6.

11.2.2.12 Applications

Nylon 6 has better properties than Nylon 6.6 due to is structure and show linearity within the proceeds to produce.

Nylon 6 has the most application like Nylon 6.6 such as,

- Industrial
- Technical textile
- Apparel
- And further sub branches of all respectively etc.
11.3 Polypropylene

Polypropylene is a synthetic hydrocarbon fiber, belongs to the Polyolefin family. The polypropylene fibers are of three categories depends on its different steric structures but having same molecular weight.

- Isotactic Polypropylene
- Syndiotactic Polypropylene
- Atactic Polypropylene

Isotactic Polypropylene

The all methyl groups are attached on only one side of the backbone plane in isotactic polypropylene.

![Isotactic Polypropylene](image)

Syndiotactic Polypropylene

The all methyl groups are distributed alternatively on both sides of the plane in Syndiotactic polypropylene.

![Syndiotactic Polypropylene](image)

Atactic Polypropylene

In Atactic polypropylene, the all methyl groups are distributed in a random way on both sides of the plane.

![Atactic Polypropylene](image)
Stress-strain Curves

The stress-strain curves of these three types of same molecular weight polypropylene fiber are different because dependence of curves on their steric structures. There is a great influence of steric arrangements on the mechanical properties of polypropylene. Isotactic and Syndiotactic polypropylenes have closely packed molecules due to regular steric structures but in the case of Atactic polypropylene, there is loose packing of molecules. So, there is a rapid increase of strain in polypropylene having Atactic structure.

Figure 57: Stress strain curves of polypropylene

Molecular structure

Polypropylene is thermoplastic in nature. Polypropylene has no polar group in its structure unlike natural and other important synthetic fibers. It is also observed that polar groups are necessary to produce high strength fibers with low molecular weights. The linear molecule chains with polar groups attract each other with strong forces e.g. in the case of polyamides, molecular weight lies between 10,000 and 30,000 to produce strong fibers.
The tensile strength, prevents slippage of linear molecular chains, is achieved by crystallinity alone in case of polypropylene and average molecular weight used is commonly higher than 200,000. So, the crystallinity plays a crucial role in tensile strength of polypropylene fibers. The degree of crystallinity of polypropylene directly depends on drawing and heat treatment.

11.3.1 Raw Material
Propylene, which is obtained from petroleum industry, is the monomer for polymerization of polypropylene. Propylene is obtained by thermal and catalytic cracking of petroleum and that’s make it low cost and unlimited availability of propylene.

11.3.1.1 Polymerization
The polymerization of propylene is done by using organo-metallic catalysts such as aluminium with titanium Trichloride at atmospheric pressure of 10 and less than 80°C temperature. This technique of polymerization is developed by Karl Ziegler and Giulio Natta. The reason behind polymerization at low temperature is to achieve high molecular weight and close packing of molecular chains.

At low temperature, there are fewer side branches which are make molecular chains to pack close and high molecular weight is also achieved. So, Ziegler-type polypropylene has high density as compared to other polymerization techniques that are performed at high temperature. This was the basic idea behind the Ziegler Polymerization technique.

![Propylene and Polypropylene Structure](image)

The organo-metallic catalyst also plays a very crucial role during polymerization. It controls the way by which the polymer is build up and that’s decide about steric structure of polypropylene mostly isotactic for smoothness and close packing.

11.3.1.2 Spinning
The melt spinning is used in the case of polypropylene polymer. The high viscosity, to obtain optimum fiber properties, molten polypropylene polymer is extruded through spinneret. After passing through spinneret, the drawing is performed to orientate the molecular chains and achieve crystals in the filament. The filaments, after passing through spinneret, are also cooled in air and then collected on bobbin. The rapid crystallization of polypropylene cause highly crystalline undrawn filaments which make polypropylene differ from other melt spun polymers like polyester and polyamides. Polypropylene fibers can be produced in form of monofilament, multifilament and staple fibers.

11.3.2 Properties of polypropylene
Table 14: Physical properties of Polypropylene

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Strength</td>
<td>3.5 - 5.5 g/den</td>
</tr>
<tr>
<td>Moisture Absorption</td>
<td>0 – 0.05 %</td>
</tr>
<tr>
<td>Softening Point</td>
<td>150 °C</td>
</tr>
<tr>
<td>Chemical Resistance</td>
<td>Excellent</td>
</tr>
<tr>
<td>Abrasion Resistance</td>
<td>Good</td>
</tr>
<tr>
<td>Elongation %</td>
<td>15 – 35</td>
</tr>
<tr>
<td>Relative density</td>
<td>0.91 g/cm³</td>
</tr>
<tr>
<td>Melting Point</td>
<td>160 - 170 °C</td>
</tr>
<tr>
<td>Thermal Conductivity</td>
<td>6.0 (relative to air 1.0)</td>
</tr>
<tr>
<td>Electric Insulation</td>
<td>Excellent</td>
</tr>
</tbody>
</table>
Tensile Strength

Tensile strength defines as the resistance of material towards break under tension. There are different varieties according to tenacity of polypropylene fibers to fulfil the varying market requirements. The crystallinity of polypropylene fibers has influence on its tenacity ranges from 3.5 – 5.5 g/den.

Elongation

The elongation at break of commercial polypropylene monofilaments ranges from 15 – 25% and multifilament yarns ranges 20 – 30% and staple fibers 20 – 35%.

Density

There are only two textile fibers, polypropylene and polyethylene, having density lower than water. The relative density of polypropylene is 0.91 g/cm$^3$.

Effect of Moisture

The polypropylene is highly hydrophobic in nature because there is no polar group within the structure of polypropylene. The moisture absorbency of fibers depends on presence of polar groups and amorphous regions. So, water does not affect the tensile strength and other mechanical properties of polypropylene.

Abrasion resistance

Polypropylene fibers have excellent abrasion resistance at dry conditions and even more abrasion resistance at wet conditions.

Softening and Melting points

The softening and melting points for polypropylene fibers are 150 °C and 160-170 °C respectively. The softening and melting points depend on degree of crystallinity which influenced by treatment of fibers after spinning.

Flammability

Polypropylene fiber melts on exposure to flame and draws away from the flame. Polypropylene is 100% hydrocarbon and will burn.

Electrical Properties

Polypropylene fiber is considered as an excellent insulating material and there are also no changes in electrical properties at high humidity because of its highly hydrophobic nature.

Thermal Conductivity

The thermal conductivity of polypropylene and some other textile fibers are listed in following table,
Table 15: Thermal conductivity of different fibers

<table>
<thead>
<tr>
<th>Fiber</th>
<th>Thermal Conductivity (relative to air 1.0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polypropylene</td>
<td>6.0</td>
</tr>
<tr>
<td>Cotton</td>
<td>17.5</td>
</tr>
<tr>
<td>Wool</td>
<td>7.3</td>
</tr>
<tr>
<td>PVC</td>
<td>6.4</td>
</tr>
<tr>
<td>Viscose</td>
<td>11.0</td>
</tr>
<tr>
<td>Cellulose acetate</td>
<td>8.6</td>
</tr>
</tbody>
</table>

Polypropylene is the warmest fiber as compared to all these commercial fibers and has lowest thermal conductivity as shown in table.

Chemical resistance

Polypropylene has excellent chemical resistance towards wide range of acids and organic solvents. Polypropylene has more chemical resistance to those chemicals which degrade other olefin fibers like polyethylene.

11.3.3 Applications

Ropes

Polypropylene is widely used in rope manufacturing. Polypropylene ropes can float in water and this proves it very valuable in some certain circumstances such as during fishing and marine operations.

Polypropylene is combinations of all properties required for rope manufacturer such as resistance to repeating loading and flexing, resistance to abrasion, minimum water absorption and lightness. There are only few commercial fibers can fulfil all these properties with high degree.

Carpets Industry

Polypropylene has naturally bulk cover factor with low specific gravity which cause its importance in carpet industry compared to other commercial fibers. Polypropylene also has high resistance to abrasion and stain resistance. The stains and dust can be easily removed by warm water and detergent.

Blankets Industry

Polypropylene is strongest, lighter and extensible fiber as compare to other commercial fibers used in blanket industry. Polypropylene has low flammability than wool and has negligible moisture regain and shows negligible shrinkage during washing.

Sewing Thread

Polypropylene fiber has high strength, excellent chemical resistance and low cost, these are factors behind its usage as sewing threads. Polypropylene yarns provide almost 65% more coverage than other commercial sewing threads of same weight per length.

Paper Industry

Polypropylene staple fibers with wood pulp are used in paper making. Polypropylene affects the appearance of paper and increases the tear strength of the paper.
Nets

Polypropylene is widely used in nets for agricultural purposes to control the amount of light, moisture and other environmental conditions. Polypropylene is also used as laundry nets. Polypropylene is very low shrinkage and can also be used after 150 washings but nylon nets cannot be used after 70 washings.

Non-woven

Polypropylene is a widely used polymer in nonwoven industry and up to 50% used in diapers and sanitary products. Polypropylene nonwovens are ideal absorbers of oil due to its oleophilic nature and high surface area.

Upholstery Fabrics

Polypropylene due to its low specific gravity, results lightness, and excellent covering factor is widely used in upholstery fabrics. Polypropylene upholstery fabrics are easily cleaned and made of 100% polypropylene.

Filters

Polypropylene is used as filters for air, gas and liquids and these applications can be seen in house as filters for air conditioning purpose or water filters. Polypropylene also used in cigarette industry as a filter in cigarettes.

Clothing

Polypropylene also used as warm weather clothing purpose, which transports sweat away from the body.

11.4 Polyurethane

Polymers science have played an important role in our daily life products like clothing, transportation, house hold accessories, and high tech applications like constructions, aerospace engineering, protection etc. Inventions of polymers in twentieth century revolutionize the material science engineering. During succeeding years, polymer science grows like an explosion with the inventions of Polyethylene (PE), Polypropylene (PP), Polyester (PET), Polyamides, Polyvinyl chloride (PVC), polystyrene (PS), Polycrylonitrile (PAN). Now these polymers are integral part of our lives.

In 1930s invention of Polyurethane polymers (PU) opened the doors for new sort of materials. Infect PU is not only a single polymer itself, it represents a class of polymers with varying properties depending upon the components. The major difference between PU and other polymers is the presence of Soft segments and Hard segments in the polymer chain, which does not exist in any polymer class. Due to this unique characteristic, it is sometimes known as segmented PU polymers. These segmented polymers can be tailored for diverse applications in the field of material engineering.

PU based materials are most commonly known as foams in market, commercially available in various forms, ranging from flexible or rigid lightweight foams to tough, stiff, and strong elastomers. Polyurethane coating on textiles have significant importance due to its functional properties. Polyurethane fibers like Lycra are commercially available, these fibers are used in textiles for compression garments, exercise apparels and sports wears due to their extra ordinary elongation strength. PU based materials are present in the shoes you stand in, the seat cushion you sit upon, the carpet backing and foam pad underlay you walk upon, the fibers of your clothing, insulation of your walls and roof, your refrigerator, dishwasher, water heater, automotive seating, automotive structural foam, automotive paints and coatings, furniture coatings, your bed mattress, and many more. Recently PU polymers are being used in high tech applications like
shape memory polymers, due to its unique segmented nature. By Tailoring the physiochemical, biocompatible, biodegradable and mechanical Properties of PU polymers scientist have made it possible to use in biomedical applications like wound dressings catheters and tissue engineering as well. PUs has also making place in composites materials.

Carcinogenicity of isocyanates, basic building blocks of polyurethane polymers, made polyurethane less productive as compare to other commercially available polymers. Most of isocyanates are banned and few are restricted for limited usage due to sever safety and health issues. Consequently, due to vital importance of polyurethane materials, researchers are now moving towards nonisocyanate based polyurethane [23].

Chemistry of Polyurethanes

Polyurethane is the general name of a family of synthetic copolymers that contain the urethane – NH-COO- linkages in their chemical repeating unit. Traditional segmented polyurethane is condensation polymerization between polyols and isocyanates. Chemically structure consist to three basic building blocks, polyols moieties are responsible for soft segment and isocyanates are hard segment of the polymer structure. By changing the chemistry and relative ratios of these two segments structural property relationship can be engineered, depending upon end use applications. Chain Extender is another primary building block they provide the mechanical reinforcement to structure.

\[
\begin{align*}
\text{Primary Building Blocks} \\
11.4.1 \text{ Polyols} \\
\text{Chemically polyols have two or more hydroxyl groups in their polymer backbone. Polyols in urethane formulation provide softness and flexibility because they have low glass transition temperature that show rubbery behaviour at physiological temperatures, therefore known as soft segment of polyurethane. Consequently, proportion of polyols in polyurethane are adjusted according to application requirement, for example 90 wt.% in flexible sealants, 70 wt.% in flexible forms and 30 wt.% in rigid insulating foams.}
\end{align*}
\]

Length and type of polyols plays an important part in resulting physical properties. There are two opportunities in Polyols structure that can be modified according to required properties. First one is polymer backbone structure that may be aliphatic or aromatic, furthermore length of carbon backbone also affects the physical as well as chemical properties of urethane. Second opportunity is number of hydroxyl groups attached to polymer backbone. The most industrially significant polyols backbones are ester and ether based but according to advancements in chemical and material engineering new polyl soft segment materials including polyalkyl, polydimethylsiloxane and polycarbonate have also been developed to fulfil the critical and specific requirements intrinsic to biomedical and industrial applications. Polyether based polyols have 71% contribution in production of Polyurethane in the world.

Polyester based polyols

First synthesis of Polyurethane in 1938 was based on Polyester based polyols. Polyester based polyols are formed by condensation polymerization of diols (EG, PG) and dicarboxylic acids (succinic acid, adipic acids, phthalic acid). They may be Aliphatic or Aromatic depending upon the nature of dicarboxylic acid. Polyester based PU are well known due to their good mechanical strength. The properties of the polyester polyol are of course a function of the diacid and diol building blocks used to produce the polymer. For example, if we use phthalic acid or phthalic anhydride for polyester based polyols, the resultant Polyurethane will have flame retardancy,
structural integrity, abrasion resistance and good insulation properties due to Aromatic structure [24].

\[ \text{Aliphatic Polyester polyol} \]
\[ \text{Aromatic Polyester polyols} \]

Polyether based polyols

The introduction of polyether polyols in 1950 led to great improvements in flexibility, comfort, stability and durability of polyurethane foams. A big advantage of Polyether based polyols are low cost, ease of synthesis and availability of raw materials. Chemically they are Poly (ethylene glycol) PEG, Poly (propylene glycol) PPG, Poly (tetramethylene glycol) PTMO. In general PEG and PPG are used conventionally in urethane formation, but PTMO recently added for specialty applications like shape memory polymers and biomedical applications. Nonpolar structural backbone and lower bending rotation energy of polyether polyols are responsible for outstanding properties like hydrolytic stability, resistance to microbial degradations, resistant to hydrolysis, high flexibility and high durability, these properties attract the manufacturers for production of polyurethane.

\[ \text{PEG} \]
\[ \text{PPG} \]
\[ \text{PTMO} \]

Polycarbonate polyols

In application to polyurethanes, polycarbonate polyols are among the highest performance polyol backbones available in the marketplace [25]. They are also among the most expensive and produced at relatively small. To face the cost challenges for production of polycarbonate polyols from phosgene, researchers have advent new routs of production from CO\textsubscript{2} gas. This rout has many advantages like cost efficiency, sustainability and comparable properties with conventional polyols.
Polyacrylate polyols

Polyacrylate polyols are differ from other polyols in many ways, these are generally limited to textile coating, wood coating and to automotive surface finishes. Polyols are preferred in the same applications where solvent resistance, toughness, and flexibility are critical. A benefit of polyacrylate polyols is glass transition temperature, which can tailored easily depending upon molecular weight and hydroxyl groups. Chemically it is copolymer of acrylic acid and methacrylic acid.

Seed oil derivative polyols

Conventionally used polyols are derivatives of petroleum components and they have many drawbacks like environmental load, health issues and high productive cost. Recently agro sciences contributed for Bio polyols. These are basically derivatives of seed oils or vegetable oils, commercially known as Natural Oil Polyols NOPs. These are synthesized from long chain fatty acid like palmitic acid, stearic acid and oleic acid linolenic acid. NOPs are used for preparation of bio based polyurethane, bio based polyurethane have wide applications in biomedical sciences.

11.4.2 Polyisocyanates

Isocyanates are another building blocks of Polyurethane synthesis. Usually known as hard segments of polyurethane. Isocyanates represents the class of chemicals that are characterized by high reactivity (readily react with active H atoms like water, alcohols, amines and polyols) and versatility. The most important isocyanate used in polyurethane manufacture is disocyanate, containing two isocyanate groups per molecule. Diisocyanatos formed linier polymer chain of polyurethane, but when the functionality is greater than two, a branched site is formed between the molecules which leads to network or cross link formation. Polyisocyanates structure may be Aliphatic or aromatic, Aromatic isocyanates TDI and MDI covers more than 90% of total production of isocyanates. Aromatic isocyanates are currently used in Shape memory polymers and medical applications.

Unlike the polyols market of which there are many varieties and continuous innovation based on structure, the isocyanates market is reasonably defined by the toluene diisocyanate (TDI) and methylene biphenyl diisocyanate (MDI) markets and their component feedstock. The global market for diisocyanate in the year 2000 was, 61.3% for MDI, 34.1% was for TDI. The expected annual growth rate is 4.6% for TDI, 5.2% for MDI, and 4.0 for aliphatic isocyanates.
Toluene Di-isocyanate TDI

TDI is cyanate derivative of toluene, cyanate groups may be on 2, 4 or 3, 5 positions of benzene ring. TDI and its derivatives are important industrial chemical as it has central role in polyurethane industry. Conventionally TDI is synthesized by reaction of Toluene Diamine TDA with gaseous phosgene. Due to health and safety concerns manufacturers are moving to non-phosgene routes of production. TDI is predominantly used to make flexible polyurethanes which are the largest application. These flexible polyurethanes are used in textiles bedding, automotive and furniture coating.

Methylene diphenyl disocyanate MDI

MDI is highly produced isocyanate for production of polyurethanes in the world market. Chemically MDI consists of two benzene rings liked through methyl group. Synthesis of MDI is almost like TDI but only ring connection is additional step by formaldehyde. MDI is used for production of rigid polyurethane foams used for insulation for your home or refrigerator, MDI can also be used as a binder for wood and to produce mold cores for the foundry industry. More than two cyanate groups lead to form cross-linked network of polyurethane.

Aliphatic Isocyanates

Need of Aliphatic isocyanates stems from the photolytic instability of aromatic isocyanate structure. Aromatic isocyanates lose their properties on exposure to light/UV. MDI based urethanes turns into yellow on exposure to light, due to benzene's light sensitive behaviour. In addition, it has been shown that the soft segment can have a significant influence on photo degradation with increased degradation occurring with increased soft segment flexibility. Primary applications of aliphatic disiocyanate polyurethane is coating due to excellent weathering. Hexamethylene diisocyanate (HMI), Isophoron diisocyanate (IPDI) and hydrogenated version of MDI are highly used aliphatic isocyanates [26].

11.4.3 Chain Extenders

Chain extenders role is to extend the sequence of alternating chain extenders and isocyanates copolymers, or extend the hard segments. Direct interactions of polyols and isocyanates produce a soft gum rubber with poor mechanical properties. These extended sequences, built the
molecular weight of polyurethane, and act both as filler particles and physical crosslink sites to increase mechanical strength. Chemically Chain extenders are of two types’ diols and diamines. Diamines gives urea linkage in polyurethane which is associated with improvement of modulus and tensile strength, but decrease in elongation of fiber.

11.4.4 Production of Polyurethanes Fibers
Polyurethane fibers commercially known as Spandex or Elastane fiber. Elastane is highly stretched and elastic as rubber. It is an elastomer, which means it can be stretched to a certain degree and it recoils when released. These fibers are superior to rubber because they are stronger, lighter, and more versatile. In fact, spandex fibers can be stretched to almost 500% of their length. Spandex fiber consists of 85% segmented polyurethane linkages. Trade names of polyurethane fibers are Lycra® by DuPont, DORLOSTAN® by Bayer, SPANZEELE® by Acrodis.

Process of polyurethane fibers production is same as other synthetic fibers spinning techniques. Melt spinning, reaction spinning, wet spinning and dry spinning have used for Spandex fibers production. Due to economic benefits and ease of handling 90% Spandex fibers are produced by dry spinning process [27].

11.4.4.1 Spinning Process
Production of spandex starts with production of prepolymer that is done under controlled conditions by mixing polyols and Polyisocyanates (usually MDI) in a reaction vessel. As composition of reacting compounds determines the mechanical properties of final fiber, so it is important to strictly control the composition of reactants. After this chain extension reaction is followed, in which prepolymer is further reacted with chain extenders. Some additives like antioxidants, stabilizers and sometime colouring agents are also added in mixture.

This viscous polymer mixture is now dissolved in suitable solvent to make dope solution. This solvent improves the flowing behaviour of polymer solution that is very important in spinning. Usually Dimethyl acetamide DMAC considered as best solvent. This dope solution is passed through the spinneret of required diameter. Long filaments of Spandex after passing through spinneret are subject to a controlled environment where liquid polymer chemically react to form a strong strand and dry out the solvent. In wet spinning process polymer solution after passing through spinneret forward to coagulation bath. In coagulation bath the solvent is precipitated and filaments are washed with deionized water followed by heat setting process.

11.4.4.2 Final Finishing
Finishing treatments are carried at the end, to avoid the sticking of filaments magnesium stearate or poly (dimethyl siloxane) finishing agent is applied which also helps in textiles manufacturing. Moreover, chlorine and light exposure reduce the overall strength of fibers, to overcome such problems special finishing agents applied on filament surface, or they may be added in dope solution during spinning process.
11.4.5 Physical properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tenacity</td>
<td>4.9 – 8.8 cN/tex</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>616-994 kg/cm²</td>
</tr>
<tr>
<td>Elongation</td>
<td>450-700 %</td>
</tr>
<tr>
<td>Elastic recovery</td>
<td>Very good</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>1.2-1.25</td>
</tr>
<tr>
<td>Moisture regain</td>
<td>1.3 %</td>
</tr>
</tbody>
</table>

11.4.6 Chemical properties

Acids

It has high resistance against cold acids but in severe conditions it is not resistive,

Alkalis

High resistance against alkalis.

Organic solvents

Good resistance against the solvents used in dry cleaning.

Insects

No effect

Micro organism

No effect
11.4.7 Applications
As mentioned earlier polyurethane have wide applications in diverse fields. End application of polyurethane depends upon the relative compositions of primary building blocks i.e. Polyols, Polyisocyanates and chain extenders. There is a huge versatility in polyurethane polymer according to hardness, stiffness and densities. It may be in the form of low density flexible foams, elastomers, hard rigid plastic and flexible fibers.

11.5 Polyvinyl Derivatives
Those compounds which contain the vinyl group and those compounds are formed by the polymerization are called polyvinyl compounds. (CH$_2$=CH−) it is basically the vinyl group. By the formation of these compounds there is no elimination of water molecules so it is an addition polymerization. There are various types of these fibers,

- Polyacrylonitrile fibers
- Polyvinylchloride fibers
- Polyvinylidene chloride fibers
- Polyvinyl alcohol fibers
- Polytetrafluoroethylene fibers
- Polyvinylidene dinitrile fibers
- Polystyrene fibers

11.5.1 Polyacrylonitrile fibers
Those fibers which are spun from the acrylonitrile copolymers are called Polyacrylonitrile fibers.

There are two sub groups of polyacrylonitrile fibers based on the percentage of acrylonitrile.

- Acrylic fibers
- Modacrylic fibers

11.5.1.1 Acrylic fibers
The fibers that are formed by the 85 % concentration by weight of the acrylonitrile monomer is called acrylic fiber.

Raw material
They are basically formed by the four methods,

- Ethylene oxide with hydrogen cyanide
- Ethylene chlorohydrin with alkali cyanides
- Dehydration of ethylene cyanohydrin
- Acetylene with HCN
Polymerization

The polymer of the acrylonitrile is formed by stirring the water and monomer solution. When the polymer is formed it can be separate out because this polymer is insoluble in water. Both processes can be used for the polymerization that is continuous and batch process. After the formation of the polymer the excess reagent can be easily recovered and reused for further manufacturing.

Spinning method

Fibers that are 100 % acrylonitrile or having 15 % of other component cannot be formed by the melt spinning because it decomposes before melting temperature.

Two techniques can be used for the spinning of acrylic fibers.

- Dry Spinning
- Wet spinning

Dry spinning

The solution of dimethyl formamide is used for this purpose. It is an organic compound. Almost 40% by weight of polymer is used for the spinning purpose and heat the solution near the boiling point of the liquid.

Then the solution passes through the spinneret and the solution is evaporated from the fibers because of high temperature and air. Then the fibers are stretched 3- 10 times to the original length. It is a continuous fiber so if staple fibers are required so these fibers are cut to the desired length.

Wet Spinning

In this method, the solution of the polymer and the solvent that is dimethyl formamide are placed in the spinneret that is dipped into the liquid bath. The liquid should be of that type which is soluble for the solvent but insoluble for the polymers is used. The solvent will dissolve into the liquid and the fiber is formed. Then it is dried, cramped and oiled.
### 11.5.1.2 Physical properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Staple</th>
<th>Filament</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tenacity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>14.1 - 31.8 cN/tex</td>
<td></td>
</tr>
<tr>
<td><strong>Tensile strength</strong></td>
<td>2100—3150 kg/cm²</td>
<td>3500—5250 kg/cm²</td>
</tr>
<tr>
<td><strong>Elongation</strong></td>
<td>Staple 20-25 %</td>
<td>Filament 30-36 %</td>
</tr>
<tr>
<td><strong>Elastic recovery</strong></td>
<td>90-95 % at 1 % extension</td>
<td>50-60 % at 10 % extension</td>
</tr>
<tr>
<td><strong>Modulus</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>353-441 cN/tex</td>
<td></td>
</tr>
<tr>
<td><strong>Stiffness</strong></td>
<td>Staple 62-88 cN/tex</td>
<td>Filament 141-362 cN/tex</td>
</tr>
<tr>
<td><strong>Toughness</strong></td>
<td>Staple 0.40-0.70</td>
<td>Filament 0.22-0.49</td>
</tr>
<tr>
<td><strong>Specific gravity</strong></td>
<td></td>
<td>1.16-1.18</td>
</tr>
<tr>
<td><strong>Moisture regain</strong></td>
<td></td>
<td>1-3 %</td>
</tr>
</tbody>
</table>

### 11.5.1.3 Chemical properties

**Acids**

Mineral acids that are in the dilute form are not affecting the fibers. Any how the fibers that are used under acidic conditions for the long time may affect the fibers.

**Alkalis**

Strong alkalis can easily attack the fibers. The NaOH, sodium carbonate and sodium bicarbonate are not attack on the fibers in the dilute form.
Organic solvents

It cannot be attacked by the organic solvents that are normally used.

Insects

Larvae cannot attack on these fibers. Fiber resist for the attack of the insects.

Micro organism

It is not attacked by the micro-organisms.

11.5.1.4 Applications
  - It is used for the knitted outwear.
  - It is used in carpets manufacturing
  - It is used in furnishing fabrics
  - It is used for the single jersey fabrics
  - It is used for the tufted pile liners.
  - It is used for sliver knit fabrics.
  - It is used for flocking, tufting and non-woven fabrics.
  - It is used for the manufacturing of papers.
  - It is used for the core of the yarns.

11.5.2 Polyvinyl chloride fibers
Those fibers that are formed by the co polymer or polymer of the vinyl chloride.

11.5.2.1 Raw material
  - Acetylene
  - Hydrochloric acid
  - Ethylene
  - Chlorine

Two methods are used for the manufacturing of PVC
  - By the reaction of Acetylene and Hydrochloric acid with the catalyst HgCL.
  - By the reaction Ethylene and chlorine and a by-product hydrogen chloride.

It is polymerized in autoclaves with the pressure of 40 - 50 ATM and 65 °C of temperature the suspension of the polymer is formed in water and removed it by the spraying and drying.

11.5.2.2 Spinning
This fiber can be spun by any of two methods
  - Dry spinning
  - Melt spinning

Dry spinning

The polymer of polyvinyl chloride is immersed into the solvent that is carbon disulphide or acetone. The temperature of the spinneret is 70 - 100 °C. The solution is passed through the spinneret and hot air is passed through the fibers extruded from the spinneret which removed the solvent and fibers of PVC are obtained. The solvent can be recovered and re used.

Melt Spinning

The polymer is melt and extruded through the spinneret. The temperature can be increased to obtain the fine yarns but it cannot be more than 200 °C because greater temperature will decompose.
11.5.2.3 Physical Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tenacity</td>
<td>24 - 27 cN/tex</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>32-36 kg/mm$^2$</td>
</tr>
<tr>
<td>Elongation</td>
<td>12-20 %</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>1.4</td>
</tr>
<tr>
<td>Moisture regain</td>
<td>Almost 0 %</td>
</tr>
</tbody>
</table>

11.5.2.4 Chemical Properties

**Acids**

No effect of acids. If these fibers are immersed in HNO$_3$, H$_2$SO$_4$ it cannot be harmed by these acids.

**Alkalis**

No effect of alkalis.

It has high resistance towards many chemicals like bleaching, oxidizing agents etc.

**Organic Solvents**

Hydrocarbons obtained from petroleum, alcohols and ethers are not attacked the fibers. But other organic chemicals can attack the PVC.

**Insects**

It is highly resistant to insects.

**Micro organism**

High resistance towards micro-organisms.

11.5.2.5 Applications

- It is use for the fishing nets, braiding, aircrafts, canvas awning, filter clothes, waddings, and tarpaulins braiding, and piping.
- It is used for the billiard clothes, artificial limbs, textile machinery accessories and saddler.
- It can be used for the filtration.
- It can be used for furnishing like awnings, tents, mosquito nettings, curtains, hammocks and insulation materials.

11.5.3 Polyvinylidene chloride fibers

In the manufacturing of these fibers vinylidene chloride is used. It is also known as saran.

11.5.3.1 Raw material

Monomer synthesis

- Vinlydene chloride
- 1,2 dichloroethane
- Trichloroethane
- Vinyl chloride
- Ethylene

These are some raw materials that can be used for the manufacturing of the vinylidene chloride. Manufacturing routes will be different depending upon the raw material. The monomer is produced as shown in fig.

Polymerization

Aqueous emulsion is used for its polymerization with a suitable catalyst by using the vinylidene chloride and the vinyl chloride as a co monomer. The range of the polymer molecular weight is 20,000-22,000 in which these fiber forming occurs.

Spinning

Melt spinning technique is used to produce the polyvinylidene chloride fibers. The melt solution of vinylidene chloride and vinyl chloride extruded form the spinneret at 180 °C.

11.5.3.2 Physical properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tenacity</td>
<td>Up to 20.3cN/tex</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>1050—3150 kg/cm²</td>
</tr>
<tr>
<td>Elongation</td>
<td>15-30 %</td>
</tr>
<tr>
<td>Elastic recovery</td>
<td>98.5 % at 3 % extension</td>
</tr>
<tr>
<td>Stiffness</td>
<td>44.1-88.3 cN/tex</td>
</tr>
<tr>
<td>Toughness</td>
<td>0.16-0.26</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>1.1-1.7</td>
</tr>
<tr>
<td>Moisture regain</td>
<td>0.1-1 %</td>
</tr>
</tbody>
</table>

11.5.3.3 Chemical properties

It shows high resistance towards bleaches and to chemicals and salt sprays.

Acids

Acids cannot attack on these fibers. It shows good resistance.

Alkalis

NH₄OH can attack these fibers and decolorize. But other alkalis have no effect on them.

Organic Solvents effect

It is not affected by the alcohols, esters, ketones, ethers and aliphatic hydrocarbons. It is temperature dependent at high temperature these solvents can be effective. It is soluble in tetrahydrofuran and cyclohexanone.

Insects

Beetles or mouth grubs are not attack these fibers.

Microorganisms

These fibers are resistant to bacteria and mildew.
11.5.3.4 Applications
It is used in upholstery, seat covers of car, furniture tape, filter fabric, handbags, luggage, beach umbrellas, manikin wigs, doll hair, grille fabrics and shade clothes.

11.5.4 Polyvinyl alcohol fibers
These fibers are formed by the polymerization on the vinyl alcohol.

11.5.4.1 Raw material
Since vinyl alcohol is an unstable material so it is produced by the indirect method. It is produced from the hydrolysis of polyvinyl acetate. Acetylene and acetic acid are used to produce the vinyl acetate.

Polymerization
It is polymerized with the help of the catalyst e.g. peroxide by dissolving the vinyl acetate into the methanol solution to form the polyvinyl acetate. After that the saponification reaction of polyvinyl acetate is done to produce the polyvinyl alcohol. After precipitation, the polymer of poly vinyl alcohol is removed from the solution and dried.

Wet spinning
Poly vinyl alcohol is normally produced by this spinning technique. The polymer is immersed into the water and form a solution. After that this solution is extruded from the spinneret that is placed into the bath containing Na₂SO₄ solution.

Dry/Melt Spinning
The other technique for the manufacturing of these fibers is the combination of both dry and melt spinning. The polymer is dissolved in water at high pressure to form a concentrated solution. Then this melt is passed through the spinneret and evaporate the solvent by the hot drawn air.

11.5.4.2 Physical properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tenacity</td>
<td>33.5. - 75.1 cN/tex</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>High strength</td>
</tr>
<tr>
<td>Elongation</td>
<td>Staple 13-26%</td>
</tr>
<tr>
<td></td>
<td>Filament 10-26 %</td>
</tr>
<tr>
<td>Elastic recovery</td>
<td>65-85 % at 3 % extension</td>
</tr>
<tr>
<td></td>
<td>50 -60 % at 5 % extension</td>
</tr>
<tr>
<td>Modulus</td>
<td>618-1589 cN/tex</td>
</tr>
<tr>
<td>Stiffness</td>
<td>150-459 cN/tex</td>
</tr>
<tr>
<td>Toughness</td>
<td>Staple 0.41-0.52</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>1.26-1.30</td>
</tr>
<tr>
<td>Moisture regain</td>
<td>4.5-5 %</td>
</tr>
</tbody>
</table>
11.5.4.3 Chemical properties

Acids
Under normal conditions the fiber is a good resistance to acids but at a high temperature mineral acids cause shrinkage and swelling of the fiber.

Alkalis
Good resistance against alkalis but it causes yellowness. It does not influence tenacity.

Organic solvents
It is resistant to most organic solvents but it is swelled by the cresol, hot pyridine and phenol.

Insects
It is high resistant towards insects.

Microorganisms
Good resistance to micro-organisms.

11.5.4.4 Applications
It has many applications in apparels, home furnishing fabrics and industrial applications. It is used in garments, denim, shirting, gabardines, linings and suiting. It is also used in gloves, dresses, socks, hats and socks. It is also used for the curtains, umbrellas, sheets, upholstery and tablecloths. Its chemical resistance, strength, durability water resistance has many important applications. It is used in hoses, ropes, tents, tyre cords, sacks and fishing nets.

11.5.5 Polytetrafluoroethylene fibers
These fibers are formed by the tetrafluoroethylene monomer.

11.5.5.1 Raw material
- Calcium fluoride
- Sulphuric acid
- Hydrogen fluoride
- Chloroform

Monomer synthesis
Hydrogen fluoride is produced by the reaction of sulphuric acid and calcium fluoride. Then the hydrogen fluoride is reacted with the chloroform to get chlorodifluoromethane. After the pyrolysis of chlorodifluoromethane at 600-800 °C desired monomer is obtained.

Polymerization
The polymer is obtained in the presence of a suitable catalyst that is peroxide under high pressure and temperature. Teflon is produced in the form of white powder. Since the reaction is exothermic so it should be controlled carefully.

11.5.5.2 Spinning
These fibers cannot be produced by the simple dry, wet or melt spinning because it degrades before melting. So, special technique is used for the spinning of these fibers. Dispersion is produced during the polymerization of this material so there form the shape of ribbon like. This dispersion passed through the spinneret placed into the bath of aqueous HCl. The particles are heated rapidly around 385 °C and remain for some seconds. These particles are transformed into polymer fibers by sintering and fusing.
11.5.5.3 **Physical Properties**

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tenacity</strong></td>
<td>9.7 - 12.4 cN/tex</td>
</tr>
<tr>
<td><strong>Tensile strength</strong></td>
<td>2205-2625 kg/cm²</td>
</tr>
<tr>
<td><strong>Elongation</strong></td>
<td>15-32 %</td>
</tr>
<tr>
<td><strong>Modulus</strong></td>
<td>123.6 cN/tex</td>
</tr>
<tr>
<td><strong>Stiffness</strong></td>
<td>132.5 cN/tex</td>
</tr>
<tr>
<td><strong>Toughness</strong></td>
<td>0.12-0.15</td>
</tr>
<tr>
<td><strong>Specific gravity</strong></td>
<td>2.1</td>
</tr>
<tr>
<td><strong>Moisture regain</strong></td>
<td>0 %</td>
</tr>
</tbody>
</table>

11.5.5.4 **Chemical properties**

**Acids**

It is completely resistance to any type of the acid.

**Alkalis**

It has no effect of any type of alkali.

**Organic solvents**

No effect of organic solvent except per fluorinated liquids.

**Insects**

No effect.

**Microorganisms**

No attack.

This extra ordinary property of the fiber is due to the carbon-carbon strong bond and the side chains are of fluorine. That’s why no chemical can easily attacked to this fiber.

11.5.5.5 **Applications**

- It is used in braided packing.
- It is used in filtration fabrics.
- It is used in gaskets.
- It is used in bearings.

11.5.5.6 **Polyvinylidene dinitrile fibers**

These fibers are formed by the monomer of vinylidene dinitrile.

**Raw material**

- Malonitrile
- Formaldehyde
- Tetra-cyanopropane

Tetra cyanopropane is produced by the reaction of formaldehyde and malonitrile and then it is heated to form the monomer of the vinylidene nitrile.
Polymerization

The polymerization is done by heating the mixture of two monomers of vinylidene dinitrile and vinyl acetate in the presence of peroxide catalyst. Polymer is obtained after precipitation and dried.

Spinning

The polymers are dissolved in the dimethyl formaldehyde solution and extruded through the spinneret. The spinneret is placed into the water bath and filaments are obtained by precipitation.

11.5.5.7 Physical properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tenacity</td>
<td>15 - 17.7 cN/tex</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>2100 g/cm²</td>
</tr>
<tr>
<td>Elongation</td>
<td>30 %</td>
</tr>
<tr>
<td>Modulus</td>
<td>176.6-220.7 cN/tex</td>
</tr>
<tr>
<td>Stiffness</td>
<td>53.0 cN/tex</td>
</tr>
<tr>
<td>Toughness</td>
<td>0.3</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>1.2</td>
</tr>
<tr>
<td>Moisture regain</td>
<td>2-3 %</td>
</tr>
</tbody>
</table>

Acids

It has good resistance against acids. At 100 °C in the 10 % nitric acid or sulphuric acid it losses 6-30 % of its strength.

Alkalis

It is resistant to dilute alkalis but can affected by concentrated alkalis.

Organic solvents

No effect of organic solvents but dissolved in dimethyl formaldehyde at room temperature.

Insects

No effect.

Microorganisms

No attack.

11.5.5.8 Applications

- It is used in deep pile fabrics.
- It is used in suiting.
It is used in knitting goods.
References


[23] Polyurethanes as Specialty Chemicals Principles and Applications Polyurethanes as Specialty Chemicals.


12. High performance fibers

12.1 Introduction
High Performance Fibers are specially devised fibers for specific application with extraordinary strength, stiffness, and resistance.[1] They are different from conventional fibers as they are technically driven for specific use. High Performance Fibers are featured for their impressively high tensile strength, modulus, Chemical and heat resistance. These include polymeric fibers such as aramids or aromatic co-polyesters, carbon fibers, glass fibers, metallic fibers and ceramic fibers.

The unique combination of various outstanding properties of High Performance Fibers are deployed in protective clothing, medical devices, automotive components, medical devices, health care products, and filter media. Use of High Performance fibers ensures faster, stronger, safer and lighter textile products.

12.2 Classification of High Performance Fibers[2]
Based on their performance properties High Performance Fibers can be characterized by their,

- Tensile Strength and modulus
- Resistance against heat and flame
- Resistance against chemicals that normally degrade conventional fibers.

12.3 Aramid fibers
The word aramid comes from the combination of two words “aromatic” and “polyamide” and according to Federal Trade Commission they can be define as “A manufactured fiber in which the fiber forming substance is a long chain synthetic polyamide in which at least 85% of the amide (-CO-NH-) linkages are attached directly between two aromatic rings.”[3]

Aramid fibers shows at-least 5-10% more mechanical strength when compared to other synthetic fibers like steel or glass fibers on equal weight basis and also keep up these properties at elevated temperatures. Aramid family includes Kevlar, Nomex, Technora, Teijinconex and Twaron.

12.3.1 Kevlar®
Kevlar is DuPont’s aromatic polyamide fiber introduced commercially in early 1970’s. Para-phenylenediamine and terephthaloyl chloride combined to form Kevlar®.[4]

Kevlar’s chemical structure typically consists of little straight rods that are closely packed together and these rods are bonded together with hydrogen bonding, thus imparting extra strength. These bonded structures actually gives Kevlar® its outstanding properties.
12.3.1.1 Properties of Kevlar®

- Mechanical Properties:
  Kevlar® has an exclusive combination of high modulus, strength and thermal stability. It was basically developed to meet the needs of everyday raising industrial and advanced-technology applications. Now, there are different type of Kevlar are available to meet extensive end uses.

<table>
<thead>
<tr>
<th>Fibre</th>
<th>Characteristics</th>
<th>Modulus (GPa)</th>
<th>Tensile Strength (GPa)</th>
<th>Extension to break (%)</th>
<th>Relative density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kevlar 29</td>
<td>Regular</td>
<td>70</td>
<td>2.9</td>
<td>4</td>
<td>1.44</td>
</tr>
<tr>
<td>Kevlar 49</td>
<td>High modulus</td>
<td>135</td>
<td>2.9</td>
<td>2.8</td>
<td>1.45</td>
</tr>
<tr>
<td>Kevlar 129</td>
<td>High strength</td>
<td>99</td>
<td>3.4</td>
<td>3.3</td>
<td>1.45</td>
</tr>
<tr>
<td>Kevlar 149</td>
<td>Ultra high modulus</td>
<td>143</td>
<td>2.3</td>
<td>1.5</td>
<td>1.47</td>
</tr>
</tbody>
</table>

Chemical Properties:

Kevlar® shows good resistant to organic solvents and aqueous solutions. However strong acids and base can degrade Kevlar if exposed for longer intervals at elevated temperature.[5]

- Thermal Properties of Kevlar:
  Kevlar® does not melt rather it decomposes. It decomposes at 427°C to 482°C in air and approximately at 538°C in nitrogen.

- Effect of Elevated Temperatures
  Enhanced temperature decreases modulus, tensile strength and elongation at break of Kevlar® yarn and fibers.[5]

On exposure to higher temperatures, Kevlar® does not show any shrinkage. Even its Co-efficient of Thermal expansion in the longitudinal direction is negligible.

- LOI
  Kevlar® is basically flame resistant but can be flare-up. Its Limiting Oxygen Index is 29.

- Effect of UV light:
  Kevlar® is sensitive to UV light. When exposed to UV radiation for longer timing, Kevlar® tends to change its color from yellow to brown.[5]

12.3.1.2 Applications of Kevlar® fiber

Kevlar®, one of the strongest material on earth has revolutionized many products and still on the way to do much more. It is being used in industry, military, sports, and safety equipment’s.

- Military Applications[6]
  Kevlar®, is best known for its use in body armour. Bullet proof vests and helmets made from Kevlar® keep wearer protected from small and large arm fires. Along with it because of Kevlar’s light weight and strength it is commonly being use in armour vehicles.
• Industrial Applications
On industrial scale, Kevlar® because of its outstanding properties is being used in the manufacturing of high temperature fluid hoses, electrical wires and cables for binding, synthetic web slings, ropes and reinforcements. Also it is used in the manufacturing of aircraft parts, ship hulls and tires.

• Sports Equipment[7]
Kevlar® is used in the manufacturing of sports equipment’s like knee hull, snow board, skate board, sports shoes, surfing boards, hockey sticks, racket strings and many others. World lightest bike helmet is also made from Kevlar. Use of Kevlar in sports equipment gives more speed, durability, shock resistance and longer shots.

• Personal Safety Equipment
Cut resistant gloves, walking boots, diving gloves, bullet and stab proof jackets, fire proof cloths are all made from Kevlar for personal safety.

12.3.2 Nomex®
Nomex® is DuPont’s first aromatic polyamide fiber made from m-phenylenediamine and isophthaloyl chloride. In Nomex®, aromatic groups are all linked at Meta position

![Nomex Fiber Structure]

12.3.2.1 Properties of Nomex®
Generally speaking Nomex® has excellent flame resistance, dimensional stability and good tensile properties. It resists degradation cause by wide range of chemicals and industrial solvents.

• Mechanical properties[8]
Nomex® fiber is strong, resilient, and flexible and shows good resistance to wear and tear.

• Dielectric Strength
Nomex® fiber can withstand short-term electrical stresses of 18 to 40 kV/mm depending upon its thickness.

• Thermal Stability
Nomex® fiber can retain its electrical and mechanical properties at elevated temperatures. Even if the fiber is exposed to 220°C continuously for 10 years, higher temperature would have no effect on its properties.

• Chemical resistance[9]
Nomex® is resistant to acids and alkalis and it remain unaffected by most of the solvents used in industry. It fits with all types of varnishes, adhesives, lubricating oils and refrigerants. As Nomex® is non-digestible, its product are safe from insects, fungi and mold.

• Cryogenic capabilities:[8]
Nomex® shows no embrittlement or degradation at cryogenic conditions i.e. -320°F because of its unique polymeric structure.
- Radiation Resistant:
  Nomex® does not show any change in its properties when exposed to high radiation area.

- Effect of UV light
  Nomex® like other natural and synthetic textile material is effected by prolong exposure to UV radiation.

- Flame resistance/LOI[9]
  Limiting oxygen Index (LOI) of Nomex® is approximately 28. It means that if NOMEX® is exposed to flame at room temperature at ambient conditions it will put off flame after flame is removed.

12.3.2.2 Applications of Nomex®[9]
Nomex® outstanding blend of textile and thermal properties made it used in wide range of thermal protective apparel. These include industrial, military, and fire fighter application.

- Industrial Applications:
  Because of its thermal resistance characteristic Nomex® Work-wear and Nomex® Comfort-wear is used in Chemical, Petrochemical, Utility worker wears where it works as a protective bar against excessive heat from fire flashes, electric arc and gives wearer time to escape off.

- Military applications:
  In military, Nomex® is mostly used for flight suits. Along with it Nomex® coveralls are used by combat vehicle crew, shipboard engineering crews, in balaclava head coverings.

- Fire-fighting applications:
  Nomex® is inherently fire resistant material and for that it is use as fire-fighter protective apparel around the globe. Nomex® apparel gives thermal protection in bunker gears, station uniforms, hoods, gloves and boots.

- Racing car drivers and support application:
  Race car drivers and their crew wear clothing with Nomex® lining to protect themselves from fires that often accompany crashes and pit accidents on track.

- Aerospace, Marine and Rail:
  Nomex® characteristics like durability, high strength, stiffness, lightweight, thermal and fire resistant made it suitable for the use in aircrafts, marine vessel and rail parts. In aircraft, Nomex® is used in the manufacturing of cabin flooring and interior, landing gear doors, wing boxes, bottle containing pressurized oxygen, engine nacelles and aircraft tires. In marine vessels it is used in bulkheads, walls and interiors.

- Heat and Insulation shields[10]
  The intrinsic thermal resistant property of Nomex® made it ideal for high temperature automotive applications. Nomex® sheet structures are use as heat and insulation shield for spark plug leads. Inside automotive Nomex® fiber maintain bays from overheating, radiator hoses from bursting.
12.3.3 Twaron

Twaron is para-aramid high performance man-made fiber produced by Teijin.

12.3.3.1 Properties of Twaron

Twaron offers well balance properties that made its products are light weight, stronger, durable and more resistant.

- High strength and modulus
  Twaron owns high strength which is two or three times more than high strength polyester and polyamide and five times more than steel when measured on weight to weight ratio. Its modulus is also far better than nylon.[11]

- Dimensional Stability
  Twaron fiber exhibits outstanding dimensional stability.

- Chemical resistance
  Twaron has crystalline structure with strong intermolecular attachment that prevent chemical from penetrating the polymer. It shows high resistance to organic chemicals while with inorganic solvents its behaviour varies with their pH value. [12]

- Thermal Properties
  Twaron shows high resistance to flame. It neither burns nor melt. If Twaron is exposed to temperature up-to 500°C for a short moment, it can survive this temperature without any symbolic loss of mass. Twaron also has the ability to carbonize in the absence of oxygen and can retain approx. 30% of its mass. [12]

- UV resistance
  Twaron is vulnerable to UV light so it is mandatory to avoid exposure to sunlight.

12.3.3.2 Applications of Twaron

Twaron is suitable for number of demanding application such as ballistic protection, heat and cut protection, in oil and gas industry, automotive industry, optical fiber cables and many more like these.

- Soft ballistic
  Twaron is integrated into bulletproof vests making it more user comfort and giving more protection against all kinds of bullets, fragments and stabs. Twaron’s high tenacity, modulus and energy absorption rate disperse the deformation waves more rapidly thus making it more suitable material for bullet proof vests.[13]

- Helmets
  Twaron are widely used in military helmets as its superior energy absorption to weight ratio, excellent strength, and durability make it most suitable for head protection.[14]
• Hard Ballistics
Twaron is also well suited material for hard ballistic. Protection, reliability and weight are the key points to be consider in the manufacturing of hard ballistic production products. Twaron based hard ballistic equipment can cover wide range risks i.e. from direct fire to shall fragments to big explosives. [15]

• Cut Protection
Industries like construction, electronics, aerospace and manufacturing usually involve handling of sharp edge or hot material that may cause injuries. Twaron protective clothing and gloves protects against cut, heat and flame. Other application include Converyer belts, Specialty paper, Ropes and cables, reinforced thermoplastic pipes, optical fiber cables, flexible flow-lines and umbilical.

12.4 Gel Spun high performance polyethylene fibers
Gel spun polyethylene fibers are ultra-strong, high modulus fibers whose bases is simple and flexible polyethylene molecule. They are commonly termed as HMPE (High modulus polyethylene), UHMWPE (Ultra high molecular weight polyethylene), UHMPE (Ultra high modulus polyethylene), and HPPE (High performance polyethylene). Its chemical formula is (CH2-CH2)n. On commercial scale it is available under the trade name of Dyneema® by DSM and Spectra® by Honeywell.

12.4.1 Properties of HPPE
• Tensile Strength
High strength and high modulus with the combination of low density are the essential characteristics of Dyneema® and Spectra®. [16]

• Density
Density of HPPE fibers is slightly less than 1. HMPE is the only high performance fiber that floats on water. [16]

• Tenacity:
The tenacity of HPPE is 10 to 15 time when compared to steel.

• Free breaking length
Dyneema® has the lengthiest breaking length in all high performance fibers that is 400km. Dyneema® and Spectra® in theory can reach to satellite orbit.

• Chemical Resistant
Polyethylene especially high crystalline-high molecular weight polyethylene is very resistant to chemicals as they do not contain any aromatic rings, or amide, hydroxylic or other chemical group that can be attacked by chemical agents. Given chart shows its chemical stability when compared against aramids. [16]

• Fatigue
HPPE is the only high performance fiber that exhibits tension and bending fatigue properties along with high tenacity. The high strength polyethylene shows resistance to repeated axial loading. [16]

• Abrasion resistance and Flex life
HPPE also shows good resistance to any kind of abrasion.

• Creep
HPPE is effected by continuous loading of weight. Deformation increase as the loading time increases that results in lower modulus and higher strain at rupture. [16]
Viscoelasticity
HPPE is viscoelastic in nature means its characteristics like elongation at break, tenacity, tensile modulus depends upon temperature and strain rate history.

Biological resistance and Toxicity
HPPE is not attacked by micro-organism thus considered as biologically inert. That’s what make it suitable for medical application.[16]

12.4.2 Applications
Outstanding combination of strength and resistive properties make it usable in wide field of applications. Some are mentioned as under,

- Ballistic protection
HPPE is widely used in ballistic applications either soft or hard ballistic. It is used in ballistic sheets as sheets made from HPPE are lighter in weight and flexible. It is also used in military helmets, vests, inserts, land vehicles, aircraft and boats.

- Safety Gloves
Safety gloves made of Dyneema® and Spectra® are more comfortable and protective.[17]

- Ropes
High strength and light weight characteristics are used in the manufacturing of ropes. For example mooring ropes of HPPE are used to secure extra-large ships on to the port like ore carriers, crude oil containers.[18]

- Sail Cloth
HPPE is most suitable for sailing cloth as its low stretch property let the sail retain its maximum shape and it also resists to abrasion, chemicals, salts and UV rays. These properties made it service life exceeds than that of any other material.[19]

- Unidirectional laminates
Dyneema® unidirectional laminate provide excellent energy absorption and improve protection at low weight Dyneema® UD is ideal for personal protection application.

- Medical applications
In medical line Dyneema® is being used in surgical implants, cardiovascular applications, ligament repair.[16] Other applications of HPPE includes Cargo containers, Air Cargo nets, slings, mountaineering ropes.

12.5 Carbon fibers
Carbon fiber is the fiber that has 92% carbon by weight in it. It has a diameter of about 0.0002 ~ 0.0004 inches. These narrow strands are bonded together in fiber axis in microscopic crystal alignment.

12.5.1 Properties of Carbon Fiber[20], [21]
- High Strength to weight ratio
Carbon fibers have the highest strength to weight ratio in all high performance fibers.

- Rigidity
Carbon fiber is rigid in nature as closed rings of carbon fibers packed together tightly.

- Corrosion resistant
Carbon fiber is mainly composed of carbon chains with no free oxygen element that can initiate oxidation process that results in high resistance to corrosion of carbon fibers.

- Electrical conductivity
Carbon fiber is an excellent electrical conductor that is because, carbon has both powers of donating and receiving electrons to complete its valence shell. Carbon fiber have carbon rings in
it. So, when voltage is applied, valence electrons move from one atom to another in order to complete valence shell of atom. This movement results in constant breaking and formation of single and double bonds that results in excellent conductivity of carbon fibers.

- **Fatigue resistant**
  Carbon fiber shows excellent resistance to cyclic loading and unloading as it has strong C-C covalent bond in its structure.

- **Tensile Strength**
  Carbon fiber possess high tensile strength as its structure has strong covalent bond in axial and longitudinal axis. But high crystallinity in its structure results in brittleness.

- **Fire Resistance/Fire Extinguishing**
  Carbon fiber is inherently fire resistance fiber because of its carbon nature. It is not only fire resistance but fire extinguishing as well.

- **Low co-efficient of thermal expansion**
  Carbon has very low co-efficient of thermal expansion which makes it best suitable for aircrafts, robotics & automotive industry.

- **Biologically Inert**
  Carbon fiber is biologically inert fiber as it has no active site or functional group available.

- **Self-Lubricating**
  Carbon fiber has very smooth surface that gives it a unique property of Self-Lubricating which increases life maintenance cycles of any automotive part if used in.

### 12.5.2 Applications of Carbon Fiber

- **Industrial Automation and Robotics**
  Carbon fiber is widely used in industry because of its light weight, low co-efficient of thermal expansion and high stiffness. These properties results in faster response time, reduced actuator and motor loads thus improving machine efficiency and lowering maintenance cycles.[22]

- **Idler rollers**
  Due to Low rotational inertia/momentum, high stiffness and low vibration, carbon fiber is used to make idler rollers which are used in many machines resulting in low roller weight, less power for running procedure & faster line speeds.[23]

- **Aircrafts**
  Carbon is being extensively used in aircrafts as it gives ultimate strength, weight reduction along with high friction resistance. In manufacturing of Boeing 787, up to 50% of carbon fiber is used in its body.[24]

- **Drones**
  Carbon fiber is now commonly being used in drone body as it is light in weight, has good vibration damping and high dimensional stability.[25]

- **Aerospace**
  Carbon fiber’s high strength to weight ratio make it most suitable material for the manufacturing of space ships and their parts.[26]

- **Wind Energy**
  Wind turbine’s blades are now mostly made from carbon fiber as it lighter, stiffer and stronger. Blades of carbon fiber proves to more efficient and speedy.[27]
• Marine Ships
Carbon fiber composites is most appropriate material for marine environment as it is tough, durable, and corrosion resistant. Masts, hulls and propellers are made of carbon fiber.[28]

• Automobiles
Carbon fiber is being used in automobile industry because of its light weight that results in quick movement. BMW is using carbon fiber in its sedan series and Ford is using wheels made of carbon fiber.[29]

• Sports good
With the use of carbon fiber in sports good, sports equipment have achieved a new level of performance. It is being used in sports bicycle, golf shafts, rackets, skies, snowboard, hockey sticks, fishing rods and baseball bats.[30]

• Architecture
Carbon fiber because of its light weight, higher strength, low elongation at break and low CTE is suitable construction material that imparts structural stability[31].

• Self-Extinguishing
Carbon fiber itself is fire-extinguishing in nature. Usually furniture fabric, mattress covers, official panel systems, seating, welding blankets, fire exposure clothing is made up of carbon fiber.[32]

12.6 High strength and high modulus fibers
In high strength high modulus fibers the basic science of structure and property relationship that was developed in aramids has been extended to form heterocyclic rigid rod polymers. In these polymers the structure is even more rigid if compared to aramids and is more difficult to process. These include melt spun wholly aromatic polyester i.e. Vectran™, PBO, PIPD and Russian aromatic fibers.

12.6.1 Zylon® PBO
PBO is the short form of Polybenzazole. It’s the world’s strongest synthetic fiber[38] whose strength, modulus and stability exceeds than any other high performance fiber. It is rigid-rod isotropic crystal polymer that was first developed in 1980’s by dry jet wet spinning process. Its cross sectional strength surpass from steel and carbon fibers.

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\text{N} \\
\text{O}
\end{array}
\]

PBO

12.6.1.1 Properties of Zylon® PBO
PBO surpass every other single high performance fiber with great margin. Its strength and modulus is around double the strength and modulus of p-aramids. Its creep resistance also exceeds from para aramids and also is very heat resistance fiber with the decomposition temperature of almost 650°C and excessively high flame resistance.[39]

• Mechanical Properties
PBO possess highest tenacity and modulus when compared to any other performance fibers. Its tenacity is 180 – 270 GPa, tensile strength is 5.8 GPa.[40]

• Creep Properties
PBO has superior creep recoveries when compared to p-aramids.

• Thermal Properties
PBO decomposes on a very high temperature that is 680°C almost 100°C more than for p-aramids.
• Flame resistance
PBO shows extremely high resistance to flame. In a vertical flame test char length is about zero.[40]

• Light resistance
PBO do not show much resistance to sunlight and it loses its strength when exposed to sunlight.[40]

• Chemical resistance
PBO remains stable in most of the organic mediums. It is stable against alkaline however it loses certain strength when exposed to strong acids.

• Compressive strength
Compressive strength of PBO is much less than tensile strength. It ranges from 0.469 to 0.561GPa.[40]

• Thermal expansion Co-efficient
PBO co-efficient of thermal expansion is negative. The fiber direction dimension decreases when temperature is raised. Co-efficient of thermal expansion of Zylon HM is about -6pm/C

12.6.1.2 Applications of Zylon® PBO[41], [42]
PBO exceptional properties make its use wide. It is being used in industry, military, protective clothing, sports and many other fields.

• Industrial applications
In industries it is being used as heat resistant felts, cable cover for welding machine, reinforcement for cements.

• Protective clothing
As PBO is extremely resistant to flame, it is commonly use as fire-fighter cloths, heat resistant garments and also use in safety gloves.

• Sports
In sports category, Zylon PBO is use in bicycle parts as bicycle Spokes and tires are made of PBO. Also table tennis racket, tennis racket, badminton rackets, Yacht ropes, snow boards, rider suits, racing cars all are made of PBO material.

• Military
In military, cords made from PBO fibers are used because of its outstanding properties. Military cord, parachute cord, military ropes and many other high spec twines made of PBO are a part of military equipment.[43]

• Tethers
Aerospace tethers and formula one tethers made from PBO are now in common use.

12.7 PVDC (Saran™) Fibers
PVDC is the short form of polyvinyl dichloride and are chlorinated fibers. Saran™ developed by Dow Chemical Company is a commercialized chlorinated fiber form by co-polymerization of vinylidene chloride and vinyl chloride.

12.7.1 Properties of Saran™
• Flame resistant
Saran™ is not only flame resistant but also inherently self-extinguishing.
• Chemical resistant
Saran™ shows excellent resistance against acids and alkalis, salts, aliphatic hydrocarbons and alcohols up-to 100°C temperature but a little less resistant to aromatic and halogenated hydrocarbons. In oils and organic solvents, it remain insoluble.[46]

• Color Fastness
Saran™ exhibit vivid colors with outstanding color fastness as before spinning pigment is added. It remains translucent and lustrous even if exposed to light and extreme weather.

• Moisture regain
Saran™ has extremely low moisture regain of about 0.1%. Thus preventing its physical properties to be effected by absorbed water.[46]

• Elastic recovery
Saran™ resist wrinkle and crease because of its high elastic recovery.

• Resistant to mold and bacteria attack
Saran™ is almost invulnerable to mold, bacteria and other insects.

12.7.2 Physical properties [47]

<table>
<thead>
<tr>
<th>Physical Properties of Saran fibers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Strength</td>
</tr>
<tr>
<td>Tensile Elongation</td>
</tr>
<tr>
<td>Young's Modulus</td>
</tr>
<tr>
<td>Specific Gravity</td>
</tr>
</tbody>
</table>

12.7.3 Application
Saran™ has broad spectrum of applications. Some of which are as following,

• It is used as chemical resistant in chemical environments.
• As Saran™ has extremely low moisture regain so it is most suitable for underwater, outdoors in rains applications, it is used in water treatment and below sea applications.
• It is being use in underground and contactor with sludge.
• It is use in the manufacturing of dry and wet filters.
• It is used in widow shades in trains and busses.

12.8 PTFE Fibers
PTFE stands for polytetrafluoroethylene and is fluorinated carbon. Teflon® is its registered commercial name by DuPont. It has a unique combination of extreme chemical and flame resistance along with low Co-efficient of friction.[48]

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\text{F} \\
\text{C} - \text{C} \\
\text{F} \\
\end{array}
\]

12.8.1 Properties of PTFE
• Superior chemical resistance properties
• PTFE has lowest co-efficient of friction in known solids.[49]
• PTFE is highly inert
• It is best electrical insulator with great dielectric properties.
• It is non-flammable.
• When placed outside, PTFE resist sunlight and weather severities.
• Do not degrade under 400F temperature.

12.8.2 Applications

- Petrochemical and chemical industry
  PTFE is used in the manufacturing of gaskets, vessel & pump interiors, washers, seals, spacers, dip tubes and well-drilling parts because of its chemical inertness and corrosion resistant nature.

- Electronics
  PTFE has excellent insulation properties along with good dielectric strength. For these properties it is being commonly used in wires, cable wraps and capacitors separator.

- Semi-Conductor Industry:
  As PTFE is highly inert and has wide operating temperature zone (-350 to 550F) it is best suitable for various items that includes chip manufacturing, encapsulation devices for quartz heaters and many more.

- Food, Beverage and Pharmaceutical industries:
  Virgin PTFE can be used in the food, beverage, cosmetics and pharmaceutical industries. Its thin sheets make an inert, no hazardous surface without any microscopic depressions where microbes can grow.[50]

- Labs
  As PTFE is inert, highly resistance to chemicals & temperature and also there is no chance of any contamination adherence. So, it is used as piping, tubing and vessels in lab ware.[50]

- Bearing pads
  Glass filled PTFE can be cut or stamped into bearing pads, and it would resist all deterioration caused by weather, however it itself remain as inert interface between disparate construction materials, like steel and concrete.

12.9 PEEK Fibers

PEEK fibers belong to the class in which there are aromatic rings within the polymeric chains locked together by comparatively inert groups. One unit of PEEK contains one ketone and two ether. It is linear, fully aromatic and highly stable structure with just carbon, hydrogen and oxygen atoms.

12.9.1 Properties of PEEK fibers

PEEK fiber is an organic thermoplastic fiber with exemplary chemical resistance along with superb mechanical and physical strength.[51]

• Thermal properties
  PEEK can perform well in the range of -60 to 260C.

• Chemical resistance
  PEEK shows great resistance to high temperature steam, fluids and chemicals reagents but it dissolves in concentrated sulphuric acid (>50%) and strong oxidizing agents such as nitric acid can degrade it.[48]

• Dimensional Stability
  PEEK is dimensionally stable material with low creep and shrinkage values.

• Polymer purity
  PEEK fibers are so pure that without any stabilizing additives they have FDA approval for medical 268 high performance fibers. They also has self-cleaning property as their surface energy is low.[48]
- Flammability and LOI
PEEK LOI is 35% and is self-extinguishing in nature. It has lowest levels of smoke and toxic gas emission.

12.9.2 Applications [52]
PEEK has a broad spectrum of application that includes,
  - Process belting
PEEK gives extends service life, low creep and low abrasion resistance to belts.
  - Filters
PEEK gives chemical resistance and dimensional stability properties to filters.
  - Wiring Harness:
PEEK wiring harnesses are light weight, naturally flame retardant, and emit low smoky toxicity.
  - Strings
PEEK strings are being used in musical instruments and racket strings because of good tensile properties and low creep.
  - PEEK Composites
PEEK is use as matrix material in thermoplastics as it improve fracture toughness for thermosets.
13. Exotic Fibres

13.1 Coir Fiber
Coir or coconut fiber is a natural vegetable seed based textile fiber extracted from the husk of Coconut shell. Coir fiber bundles are divided into following categories:

- White Coir
- Brown Coir

Coir is either traded as raw fiber bundles or it is processed into products like brushes, twine, matting, geotextiles and upholstery. The one of the two most important seed fibers other than cotton is the coir fiber. Coir is the material in the form of fibers which is obtained in stiff internal and outer surface of a coconut.

13.1.1 Structure
The structure of the coir fiber is shown as per following. The wall of the coir fiber cell is a two-layer structure. After primary wall comes the secondary wall which is donated with S1, then comes the secondary inner wall is donated with S2 at a certain angle to S1. Then comes the inner most wall donated by S3 which is again at an angle to S2. These spiral angles of the cell wall are the reason of its high extensibility. [53]

![Figure 58: Structure of Coir fiber](image)

13.1.2 Fiber Manufacturing Process
Coir fiber is obtained by following processes

13.1.2.1 Harvesting and Husking
First of all the coconut is harvested by hand or picked up after it fell from tree having ripened. 2 coconuts are husked immediately. The surface of pulp can be removed quiet easily. Husking can be done by hand or by machines. Latest husking machines can produce 2000 coconuts/hour. [53]-[55]
13.1.2.2 Retting
Retting is a type of curing process in which husks are kept in an environment that starts the action of naturally existing microbes. This particular process rots the husk's pulp partially which in results allow the separation of coir fibers and a residue which is named as coir pitch. Two types of retting techniques are normally used.

- Freshwater retting
- Saltwater retting
Fresh-water retting is used for completely ready coconut husk and saltwater retting is utilized for green husk. Mechanical methods have been in use recently to accelerate or eliminate retting.

13.1.2.3 De-fibering
Separation of fibers from pitch is called De-fibering. The clean fibers are placed on ground for drying in the light of sun.

13.1.2.4 Finishing
Fibers are pressed mechanically to form a bail. The fibers are then carded or combed as per requirement and thick yarn is formed. Later on spinning can be done by simple hand spinning machine or a fully automated spinning machine. [53]-[57]

13.1.3 Properties
The properties of the coir fibers are as follows,

- The fiber is of 0.3 to 1 mm length and 0.01 to 0.02 mm in diameter
- Density is 2057 kg/cub. Meter
- Elongation is 17.3%
- Thermal conductivity is 0.05W/m.K
- It is little stiff in nature
- It has high tenacity.
- Its absorbency is similar to jute fiber
- Specific gravity is 0.87
- Tensile strength is 210MPa
- Elongation at failure is 27.4%

13.1.4 Applications
The applications and use of coir or coconut fiber can be seen as follows,

- Red is mostly utilized in the making of floor mats, doormats, brushes, mattresses, floor tiles and looting.
- A significant portion of brown pillows Wreath sprayed with latex rubber that binds the fibers together which are used as the filling of upholstery, for the automotive sector in Europe.
- The substantial is extensively used for purpose of insulation and packaging also.
- The main use of coconut fiber in white form is the manufacturing of rope. Mats weaved from coconut fiber is manufactured of the finest qualities of brushes and white fiber consuming hand or mechanical looms.
- White coconut is also utilized to manufacture the fishing nets because of its immense opposition to salt water.
- It has been found that coconut Mexico contains many colonies of Aspergillus terreus beneficial fungi which plays as an organic regulator agent against pathogenic molds of plants.
- The coconut is also used as a substance for growing burgeons. The coconut is normally mixed with vermiculite boiling water. Afterward the mixture coconut is chilled to room temperature, located in a larger container, typically a plastic box.
After spawning previously prepared jars are added, spawning normally done in jars using substrates such as rye grains or seeds of "wild birds".

The fungus is mycelium of fungi and colonizes the coconut mixture / vermiculite mushrooms will eventually bear fruit. [59]-[60]

The coconut is an allergen and latex and other such materials commonly used in the handling of coconut.

Coconut can be utilized as a substrate for reptile terrarium.

Dust coir or coconut oil can contain large amounts of water just like a scrubber.

It is also utilized as a substitute for normally used mulch mixtures, or as a substrate for soilless farming of the plant.

It has been called "coco peat" because it is fresh coconut fiber bit like what is sphagnum peat, although it is not true peat.

"Coco Peat" also serves as a “Soil Conditioner”. Because of the less levels of nutrients in its manufacturing, Coco peat is normally not the only component of the medium which is utilized to grow plants.

It is used as a substrate terrarium for reptiles and arachnids

13.2 Mohair
A “Silk-like-Fiber” that is obtained from “Hair of Angora Goat” is termed as Mohair. Mohair is best known for the following properties or characteristics,

- Good thermal insulation and is 35% warmer than wool
- It is very poor in absorbency
- Very good in comfort properties
- Good fall and the feeling is luxurious
- It is 10% stronger than wool, making it durable.
- Very good resistance to wrinkles

In the meantime, solid and safe, mohair is known for its high shine and sparkle which has given it the moniker "Fiber Diamond" and is frequently utilized as a part of fiber mixes to add these qualities to a material. Mohair retains color particularly well. Mohair is hot in winter since it has phenomenal protecting properties, while staying cool in summer because of its dampness engrossing properties.

It is strong, normally flexible, fireproof and impervious to wrinkles. It is thought to be an extravagance fiber, for example, cashmere, angora and silk are for the most part more costly than most sheep fleece. Mohair is applauded by some other one of a kind property: it is hotter than different strands, notwithstanding when used to make a lightweight packaging, and is regularly blended with fleece for it; Mohair filaments and has an unmistakable brilliance made by the way they reflect light. [57]-[58]

In mix with the capacity to retain the mohair colors outstandingly well, the unadulterated mohair yarn is for the most part unmistakable by its clear and soaked hues. Youthful goat strands are the mildest and used to deliver yarn for garments. Fiber of develop goats used to make things, for example, covers. Mohair is likewise utilized as a part of ” artificial hide ” for skiing and cross country skiing. The mohair utilized on a sweeping permits the skier a fitting climb strategy without sliding downhill.

13.2.1 Structure
The structure of the mohair fiber is shown as below. Overlapping scales composed of cuticle cells surrounded the cortex each having a free edge that points to the tip of the fiber. The scales consist of three distinct layers named as epi-, exo- and endocutile and form a protective coating around the cortex.
13.2.2 **Fiber Extraction process**
- Shearing is done in which fleece of the sheep is removed along with a thin layer of the skin. Shaving off the hair is also done in hot weather where sheep can live without its protective coating.
- After shearing scouring is done to separate the dirt and grease from the fleece.
- In sorting fleece is separated according to their texture.
- After sorting the fiber which is called burr is picked out from hair.
- Now dyeing is done to get the required color.
- After dyeing spinning is done to form a yarn of the fibers.

13.2.3 **Properties**
The properties of mohair fibers are as follows,
- Its structure is most durable of all animal fibers so it can easily be processed without any harm to physical structure of fiber.
- It's resistant to dust because it is slippery in nature and dust does not stay on these types of fibers.
- Mohair fiber can be dyed easily and that too excellently.
- It has reflecting properties thus giving a sheen effect.[54]
- Mohair is almost non-flammable.
- It is the most resilient textile fiber.

13.2.4 **Applications**
- Mohair is a glistening fiber with a velvety, lavish appearance however it is likewise hard wearing.
- Singular filaments are solid and make a completed texture that is non-crushable, soil safe and does not pill.
- It can be utilized both for dress and outfitting and, inside these, its end uses are colossal.
- One of the difficulties confronting the mohair business - especially the weaving segment - is that the fiber has been imitated by substantially less expensive acrylic yarns, created to have comparable properties and depicted as "mohair-prefer". These items are believed to have done real mohair an insult, corrupting its astounding picture.
- One of the benefits of this fiber is its enormous flexibility.
- Mohair has a liking for colors and can retain them totally and permanently.
- Mohair upholstery velours are picked in light of the fact that, albeit costly, the texture is to a great degree hard wearing and simple to clean while making a sentiment quality.
- Around 12 for each penny of aggregate mohair creation goes into outfitting textures, for example, upholstery velours and moquettes. Such textures are regularly utilized for...
upholstery, especially in esteem areas - including the top notch ranges of boats, for example, the QE2.

- It is frequently mixed with fleece for top quality covers where the mohair content makes the texture hotter, and in the meantime lighter.
- It gives warmth amid the winter months additionally makes a cool suiting texture for the stickiness of summer, consequently its prevalence in the Far East, especially Japan.
- Mohair is utilized to make numerous items - including weaving yarn for hand or machine knitwear, lightweight suiting, texture for stoles, scarves and warm covers and tough upholstery velours.

13.3 Cashmere
It is a fiber that is obtained from “cashmere goats”. Fine under hair is one of the softest and fleeciest fibers available. Cashmere is demanded worldwide for making luxury textile products. The most important characteristics of cashmere are as follows.

- Excellent thermal insulation so it is very warm by generic
- Absorbency is very slow
- Comfort properties are excellent as it is very soft and luxurious
- Drape is very good
- Good crease resistant and good elasticity
- Expensive due to limited supply
- Typically it is blended with wool. Silk or polyester

Cashmere feels incredibly soft-silky & smooth. It is also incredibly warm, having insulating properties, so it can also be comfortable for use in the transitional seasons. [58] [63] [65]

13.3.1 Structure
Structure of cashmere wool fiber is shown as below. Cashmere has a predominance of orthocortical and mesocortical cells. Cashmere wool has more mesocortical-cells and has a more microfibril packed density and thus imparting cashmere a property of showing low crimp than other fibers of wool.

13.3.2 Properties
- Cashmere made textiles drape beautifully and have a quality nap.
- Fiber is cylindrical, soft and silky.
- Elongation at break is 25-35% and in wet conditions it ranges from 25-50%.
- Elastic recovery is very good.
- Specific gravity is 1.3-1.32.
- Standard moisture regain is 16-18%.
- It decomposes at 130 degree centigrade and chars at 300 degree centigrade.
- It is attacked by acids and decomposes completely.
- It is not affected by organic solvents.
- It is affected by insects.
- It is dyed by basic dye direct dye and acid dye.

13.3.3 Applications
- “Camping and Sports Equipment – Cashmere is some of the time consolidated with different materials and utilized as a part of outdoors tangles. It is likewise now and again utilized for making socks for extraordinary utilize, for example, for skiing or climbing.”
- “Cashmere coats are light, yet warm, and fantastically delicate. They likewise take into account great development as they aren't hardened. Costs can change enormously from a couple of hundred dollars to thousands contingent upon the nature of cashmere utilized and whether it was made by a specific planner mark.”
- “Cashmere sweaters are exceedingly looked for after as they are sufficiently thin to be worn over a shirt, yet effortlessly under a suit. They give a decent level of warmth to the
wearer in respect to their thickness, while giving a quality of tastefulness. They are accessible in a wide assortment of styles and hues.”

- “Cashmere suits are accessible, despite the fact that the cashmere is regularly joined with different fleeces/textures to make it all the more hardwearing.”
- “Rugs, Carpets and Bedding – Cashmere that isn’t reasonable for apparel is frequently utilized for making little mats. This cashmere is typically coarser than that which is utilized for pieces of clothing. Cashmere covers are additionally prominent, yet the cost of the cashmere texture can make them to a great degree costly.”
- “The larger part of cashmere is utilized as a part of attire. It is a perfect texture as it is generally light weight, additionally moderately warm.”
References


[37] S. A. Beda Ricklin, “Vectran fibers &amp; yarns for demanding high strength applications.”


