# Chapter 2
# Fibers for Technical Textiles

**Sheraz Ahmad, Tehseen Ullah, and Ziauddin**

**Abstract** Technical textile products are designed for their functional property rather than their aesthetic properties. The selection of the right material is very important while manufacturing technical textile products. The selection of material depends upon the required function, nature, and severity. Different types of fibers are used in technical textiles; they are broadly categorized into two types, natural and man-made fibers. In natural fibers' category, the most used are flax fiber, jute fiber, hemp fiber, and ramie fiber due to better mechanical properties; in comfort application, cotton fiber may be used; and in hometech, silk fiber is used due to its excellent drapability property. In man-made category, the fibers used are polyester, nylon, carbon, polypropylene, glass fiber, viscose fiber, acrylic fiber, protein fiber and metal fiber. Some other advance fibers which are used in technical textile products like auxetic fibers and nano fibers are discussed in this chapter.

## 2.1 Introduction

Technical textiles are the materials which are primarily designed for their functional property or technical performance rather than their aesthetic properties or decorative purpose [1–3]. Application of fibers in technical products increases as compared to non-textile materials due to some significant properties of fibers like,

1. Textile fibers are flexible.
2. It has excellent mechanical properties along the axial direction.
3. It has a high value of the specific surface area.
4. Textile fibers as compared to other materials can easily be converted into different structures like woven or nonwoven structures.

In the technical application, the high surface area of fibers plays an important role, in advance technical application. The performance cost to a ratio of fibers keeps maximum during the developmental process. The properties of fibers depend on

S. Ahmad (✉) · T. Ullah · Ziauddin
Faculty of Engineering and Technology, National Textile University, Faisalabad, Pakistan
e-mail: itsadeelnaz@hotmail.com



S. Ahmad et al. (eds.), *Fibers for Technical Textiles*, Topics in Mining, Metallurgy and Materials Engineering, https://doi.org/10.1007/978-3-030-49224-3_2

several factors like materials of fibers, the orientation of fibers and hybrid structure may also play a role in the performance of fibers and their application in technical products [4]. Textile fibers are majorly divided into two main categories:

1. Natural fibers
2. Man-made fibers.

## 2.2 Natural Fibers

Chinese and Egyptians are the first to utilize the natural fibers in technical applications, using mats of papyrus as reinforcement in the foundation during the construction of worship places such as Buddhist temples and Pyramids [5, 6]. In light of the significant use of natural conventional fibers in technical applications, initially, this chapter is related to discuss the natural fibers, their structures, physical and chemical properties, and their versatility in scope. Some natural fibers are discussed below.

### *2.2.1 Cotton Fiber*

Cotton fiber is known as the king of fibers, its consumptions in the world are half of the whole fiber's consumptions due to its distinctive properties, and low cost [7].

#### 2.2.1.1 Chemical Structure of the Cotton Fiber

The cotton fiber structure is the long chains of natural cellulose consisting of oxygen, carbon, and hydrogen, also known as polysaccharides. The properties of cotton fiber like ultimate strength depend on the length of chains. The repeating unit of cellulose in an average chain is about 10,000 and the length of the chain is approximately 2 mm. Molecular chains combine through hydrogen bonding intermolecular forces to form microfibrils which further join to form cotton fiber [8]. The chemical structure of cellulose is shown in Fig. 2.1.

Cotton fiber popularity is due to its natural source and biodegradable nature, unique aesthetic and physical properties. SEM images of a longitudinal and cross-sectional view of cotton fiber are shown in Fig. 2.2.

The longitudinal view of cotton fiber is just like ribbon and the cross-sectional is like beam shape.

#### 2.2.1.2 Physical Properties

Physical properties of cotton fiber are given below:

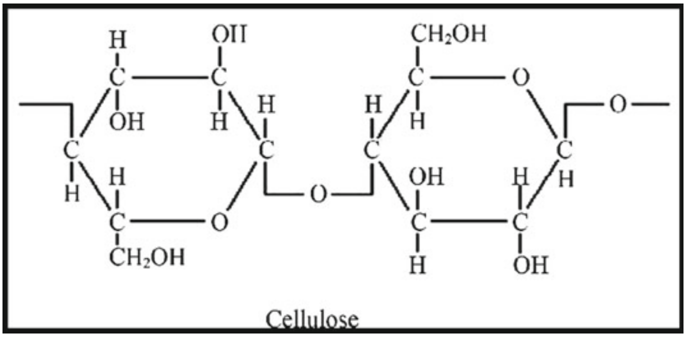


**Fig. 2.1** Chemical structure of cellulose

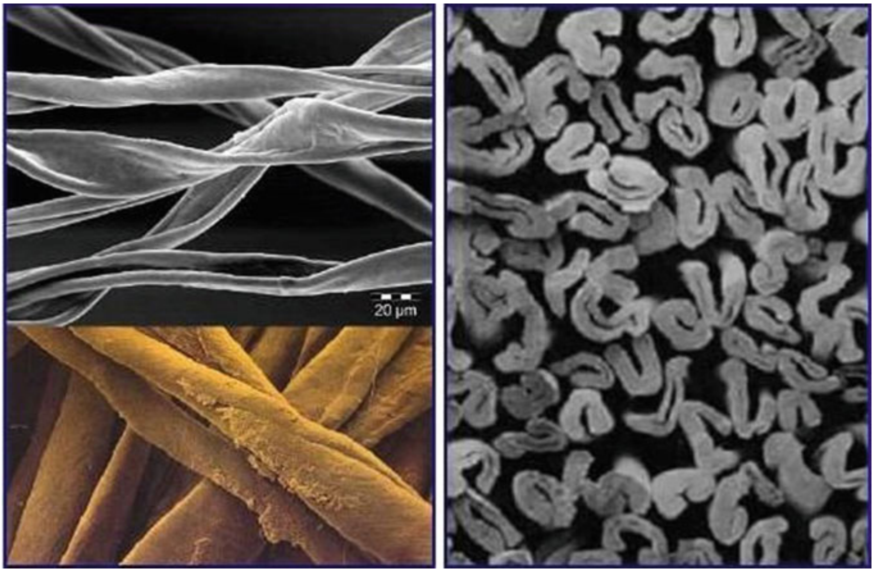


**Fig. 2.2** Cross-sectional and longitudinal view of cotton fiber

***Color***: The color of cotton fiber could be white, half-white, creamy white, slightly grayish.

***Tensile strength***: Tensile strength is the ability of a material to withstand against the applied force. Cotton fiber has moderate tensile strength. The tenacity of cotton fiber ranges from 3 to 5 gm/den, in wet form cotton fiber has 20% greater tensile strength than in dry form. It's due to hydrogen bonding created in wet cotton by the addition of moisture.

***Elongation at break***: Cotton fiber has a low elongation at break equal to 5–10%.

***Elastic recovery***: The ability of a material to restore its initial position is called elastic recovery. Cotton is rigid. At 2% extension cotton fiber has an elastic recovery of 74% and at 5% elongation, the recovery comes to 45%.

***Specific gravity***: The specific gravity of cotton fiber is 1.54.

***Moisture regain***: The standard moisture regain of cotton fiber is 8.5%.

***Heat effect***: Cotton has excellent resistance against heat degradation, at 120 °C temperature for many hours the cotton color turns to yellow color. It starts decomposing at 150 °C. Cotton can burn easily in the open air.

***Effect of sunlight***: Cotton is degraded by the UV regain and shortened waves of visible regain of sunlight.

***Effect of age***: If cotton is stored for 50 years carefully then it will slightly lose the properties as compared to fresh cotton.

#### 2.2.1.3 Chemical Properties

Chemical properties of cotton fiber are given below:

***Effect of acid***: Hot dilute acid or cold concentrated acid affect the cotton fiber.

***Effect of alkalis***: Cotton shows good resistance against alkalis. In NaOH solution cotton swells instead of damage.

***Effect of insects***: Insects, beetles, moth-grubs cannot attach to cotton fiber.

***Effect of micro organism***: Cotton has poor resistance against microorganisms. Fungi and bacteria attach to cotton fiber.

Different finishes can be applied to enhance the performance of cotton-like pyrovatex [9] and proban [10] to make fire retardant cotton. Some other properties of cotton like high absorbency, soft feel, and high wet modulus.

## 2.3 Bast Fibers

Bast fibers are the fibers extracted from the stem of the plant. It also falls into vegetable fibers category. The important fibers that belong to this class are flax, hemp, jute, ramie, hemp, and kenaf fibers [11, 12]. The details of these fibers are given below.

### *2.3.1 Flax Fiber*

The bast fiber extracted from the stem of the Linum usitatissimum plant is called flax fiber. It is used in the manufacturing of linen fabrics. The flax fiber plant grows up to 4 ft high, and the fibers are present in the below part of a plant. The fibers are separated from woody materials through a process called retting, in which the hard-wood materials are separated from the fibers. Retting can be done by using chemicals, or through natural processes. After the ratting process, fiber materials pass through the scutching and hackling process. Flax fiber's length is 30–38 cm in length. The production of flax fibers is about 1/7th of the jute fibers. But it is considered more important than bast fiber due to its usage in linen fabric manufacturing [8, 13].

#### 2.3.1.1 Flax Fiber Chemical Composition and Structure

Figure 2.3 shows the chemical structure of the flax fiber. Composition of flax fiber is majorly consisting of cellulose 75%, while hemicellulose 5%, lignin and wax are 4% and #% respectively, ash 0.5%, and the content of water is 12.5%. The repeat unit of flax fibers is 18,000 on an average, which is much greater than cotton. Cotton has 5000 average repeat units in a single polymer chain. Flax is about 18,000 micrometers in length and thickness about 8.8 NM [14].

Chemical and physical properties of flax fiber:

**Length**: The length of flax fibers ranges from 90 to 125 cm.

**Color**: The color of flax fiber varies from brownish ivory to yellowish gray.

**Tensile strength**: Tenacity of flax fiber in the dry condition is 2–7 gm/denier while in wet form the strength increases 20% like cotton fiber ranges from 2.5 to 9 gm/denier.

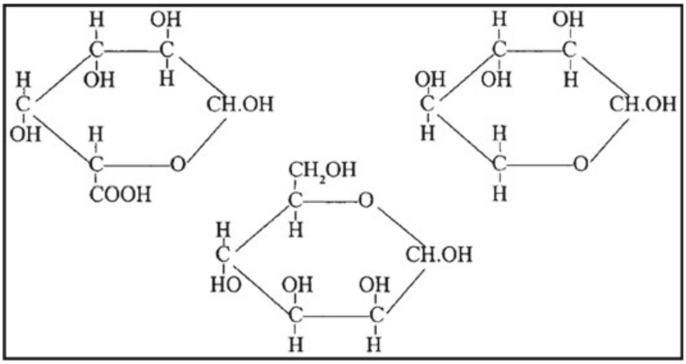

**Fig. 2.3** Chemical structure of flax fiber

**Elongation at break**: In the wet form, its elongation at break percentage is 2.2% while in the dry form its elongation at break is 1.8%.

**The specific gravity of flax**: 1.54 like cotton fiber.

**Moisture regain**: Standard moisture regain of flax fiber is 12%.

**Effect of sunlight and hear**: Sunlight degrades the flax fibers slowly, the effect of temperature on flax fiber is similar to cotton fiber.

**Abrasion resistance**: Fair to good abrasion resistance of flax fiber.

**Dimensional stability**: Flax fiber shows good dimensional stability, but creases are easily produced on flax fabric.

#### 2.3.1.2 Chemical Properties of Flax Fiber

**Effect of acids**: Concentrated acids easily degrade the flax fiber while in the case of dilute acid the effect is reduced if washed immediately.

**Effect of alkalis**: In the case of alkalis the flax fiber shows strong resistance against alkalis.

**Effects of bleaches**: Flax fiber shows good resistance against hypo chloride and cool chlorine bleaches.

**Dyes**: For flax fiber dying vat and direct dyes are used.

### *2.3.2 Flax Fiber Application in Technical Textile Sector*

Flax fiber is used to produce linen fabrics. The uses of linen have changed dramatically since 1970. 70% of linen produced in 1990 was used in apparel textiles. It also has various applications such as:

1. Table wear
2. Suiting
3. Surgical thread
4. Sewing thread
5. Bed linen
6. Kitchen towels
7. High-quality papers
8. Handkerchief linen
9. Shirting
10. Draperies
11. Wallcoverings
12. Artist's canvases

13. Luggage fabrics
14. Paneling
15. Insulation
16. Filtration
17. Fabrics for light aviation
18. Automotive end uses
19. Composite boards.

## 2.4 Jute Fiber

### *2.4.1 Introduction*

Jute is another bast fiber, due to its golden-brown color it is also known as golden fiber. The extraction of jute fibers is like flax and other stem fiber. The majority of the jute fiber is extracted from the plant Corchorus capsularis, a lesser quantity of jute fiber is also extracted from Tossa jute. Jute fiber is an annual crop. It takes 120 days April/May–July/August to grow. Jute fiber structure is mainly composed of lignin, cellulose, and hemicellulose. Due to the presence of lignin in structure it is a harder fiber than cotton and other fibers. For the spinning process of yarn, the emulsion is done to make it soft. Jute fiber is a long and shiny fiber, its length varies from 1 to 4 m and 7–20 microns in diameter. Jute is the second most-produced fiber after cotton fiber.

### *2.4.2 Environmental Benefits*

Jute fiber is an environment-friendly fiber due to its completely biodegradable nature and recyclability. Jute fibers on one hectare consume about 15 t of carbon dioxide ($CO_2$) gas and release about 11 t of oxygen in the atmosphere. Its cultivation enriches the soil fertility for the next crop. During the burning jute fiber does not generate harmful gases.

### *2.4.3 Physical Properties of Jute Fiber*

- **Jute fiber length**: The length of jute fibers varies from 5 to 12 ft.
- **Fibers color**: Jute fiber is available in different colors like, off-white, white, golden, brown, and gray.
- **The tenacity of fiber**: Jute fibers have good strength, the tenacity of fibers is 3–4 gm/den.
- **Elongation %**: The elongation at break of jute fiber is 1.7%.

- **The specific gravity of jute**: 1.5 is the specific gravity of jute fiber.
- **Standard moisture regains**: The moisture regain of jute fiber is 13.75% mush higher than cotton fiber.
- **Resiliency**: Jute fiber has bad resiliency.
- **Dimensional stability of fiber**: Jute fibers have average dimensional stability.
- **Light and heat**: The effect of heat and light on jute fiber is average.
- **Microorganism**: The effect of microorganism on jute is good as compared to cotton.
- **Abrasion resistance**: Average abrasion resistance of jute fiber.

### *2.4.4 Chemical Properties of Jute Fiber*

- **Effect of acid on jute fiber**: Concentrated cold acid or hot dilute acid easily damaged jute fibers.
- **Alkalis effect on jute fiber**: Strong alkalis affect the jute fibers and damage it easily. In the presence of caustic soda jute fibers when heated, loses its weight.
- **Effect of bleaches on jute fibers**: It shows good resistance against bleaching agents like $KMNO_4$, $H_2O_2$, etc.
- **Effect of light on fibers**: sunlight changes the color of fibers; it changes its color due to the presence of lignin in the structure.
- **Mildew effect on fibers**: as compare to cotton and flax, jute fiber shows good prevention against mildew.
- **Dyeability of jute fibers**: for dyeing of jute fibers basic dyes are used. Its dyeing process is also easy.

### *2.4.5 Application of Jute Fibers in Technical Textiles*

After cotton fiber jute is the second most important natural fiber, not only due to cultivation but also due to its versatile applications. Due to some unique properties like bulkiness, heat and sound insulation, high tenacity, high thermal resistance, and good antistatic properties, all these properties make it suitable for use in technical textile applications. Some applications are given below.

Jute fiber is the natural, biodegradable fiber, and after cotton second most cultivated fiber in the world. Jute fiber is used in different applications like in the lining of shoes, motors, canal, and boots. Cables and ropes are made from it. Filter clothes are also made from jute fibers. It is used as packaging bag for rice, wheat, etc. Jute fiber is used as wrapping material for steel and iron tubes or rods, needle felts are made from jute fibers, heavy type aprons are made from it. Camp clothes, horse covers, tarpaulins, and in bedding foundation jute fibers are used. It is used in sacks, bags and bailing and bundle clothes as well. Jute fiber is used in roofing felts, covering fabrics, in the tire as wrapping material, it is used as a foundation in Upholstery, different types of strings are made from jute fiber. In the technical textile sector Agrotech and in Geotextiles jute fiber is widely used, due to its environment-friendly nature throughout its life cycle from seed to fiber. To control soil erosion jute woven fabrics are used. It is used in seed protection and weed control applications.

## *2.4.6 Ramie Fiber*

### 2.4.6.1 Introduction

Ramie fiber it can be pronounced as Ray-me is the natural vegetable fiber. Chemically, it is classified as cellulose fiber, just like rayon, cotton, and linen fibers. It is one of the oldest natural fibers. Egyptian people used ramie fibers in mummy cloths during the 5000–3000 BC period. Many centuries ago it had been grown in China. Ramie is commonly known as a group of white ramie, rhea, china grass, and green ramie, belong to the bast fiber category. The plant from which Ramie fiber was extracted belongs to Urticaceae or Nettle family. These plants up to six times can be harvested annually. It produces many unbranched stems from underground rhizomes and has a crop life of 6–20 years. Chemical treatment was required to remove pectins and gums from fibers. The fabric manufacturing of ramie fibers is similar to the manufacturing of linen fabric from flax. The leading producers of ramie fibers all over the world are China, Korea, Brazil, Philippines, and Taiwan. Ramie is mostly in the blended form with other natural fibers like cotton, wool, etc., to develop fabric both woven and knitted, fine just like linen, and coarser like canvas [15, 16] (Figs. 2.4 and 2.5).

Ramie Fiber physical properties:

- In natural fiber, ramie is considered one of the stronger fibers.
- In the wet form, it increases its strength.
- Moisture regain is similar to linen fiber.
- Ramie fiber is not durable, so it is mostly used in blend form with cotton and wool.
- Ramie fiber has its ability to hold shape, excellent wrinkling resistance, good luster property like silk [17] (Table 2.1).

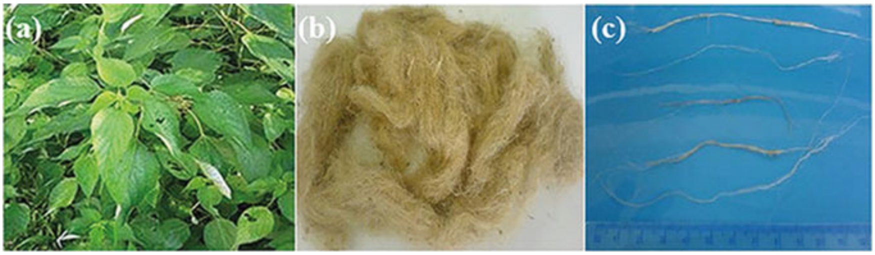


**Fig. 2.4** The typical ramie plant (**a**), bunch of ramie fibers (**b**), and separated ramie fibers (**c**)

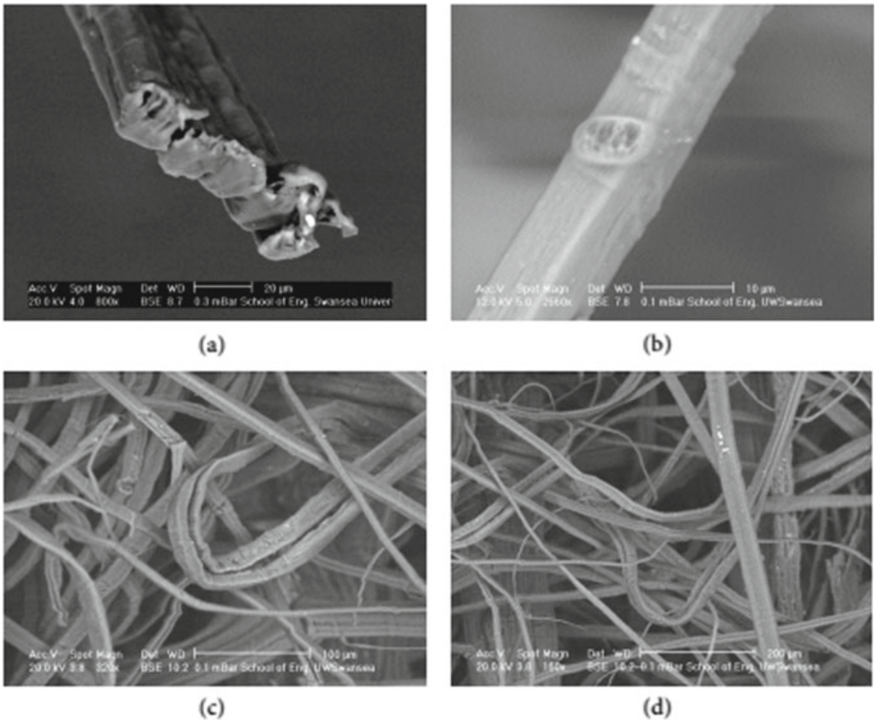


**Fig. 2.5** SEM micrographs of a hemp fibre bundle, (**a**) and (**b**), and loose fibres, (**c**) and (**d**)

**Table 2.1** Advantages and disadvantages of Ramie fiber

| Ramie fiber advantages | Ramie fiber disadvantages |
|---|---|
| Resistant to microorganism | Low in elasticity |
| High moisture regain | Lacks resiliency |
| The dyeing process is easy | Low abrasion resistance |
| Ramie fiber increases in strength when wet | Stiff and brittle |
| Withstands high water temperatures during laundering | Low in elasticity |
| Smooth lustrous appearance improves with washing | Lacks resiliency |
| It keeps its shape and does not shrink | |
| It can be bleached | |

**Table 2.2** Hemp fiber composition

| | |
|---|---|
| Alpha-cellulose | 62–67% |
| Hemicellulose | 8–15% |
| Lignin | 4% |
| Ash | 5% |
| Wax | 1% |

## *2.4.7 Application of Ramie Fiber*

Ramie area of application is very versatile, used in napkins, tablecloths, and clothing. Blended with cotton it is used in sweaters. It is also used in fishnets, upholstery fabrics, fire hoses, canvas, and straw hats.

## *2.4.8 Hemp Fiber*

### 2.4.8.1 Introduction

Hemp is the ancient used first by Asian countries before the birth of Christ. It is the bast fiber just like the kenaf, ramie, flax, and jute. Primary and core hemp fibers are attached with each other through a glue-like soluble material called Pectin. Primary hemp fibers are used as reinforcement in composites, in paper industry, and as a pulp. While the core hemp fiber is used as building materials to reinforce the structure, it can be used as animal quilt and garden covering. The composition of hemp fiber is shown in Table 2.2 [18, 19].

It is the annual plant which grows from seed. Hemp is the environment-friendly fiber which can grow without the need of pesticides, fertilizers, and herbicides. Hemp plays an important role in the sustainable future, as in case of cotton we required large amount of chemicals which are not only harmful to human beings but also a danger to the environment. Only cotton crop consumes 16% pesticides sprayed in the world. Hemp due to its deep root system also gives strength to soil and protects it from erosion. Hemp fiber is strong, lustrous, light color, and fine fibers, which are obtained from a plant called "cannabis sativa." After spun the hemp fiber becomes thicker and coarser as compared to flax fiber. Due to its high strength it is used in technical products like carpets, ropes, and rugs [20] (Fig. 2.6).

### 2.4.8.2 Producing Countries

Hemp fiber is grown in countries like USA, Canada, Belgium, France, Holland, Hungary, Australia, China, Thailand, Italy, Russia, Philippine, West Indies, Mexico, India, and Germany [19].

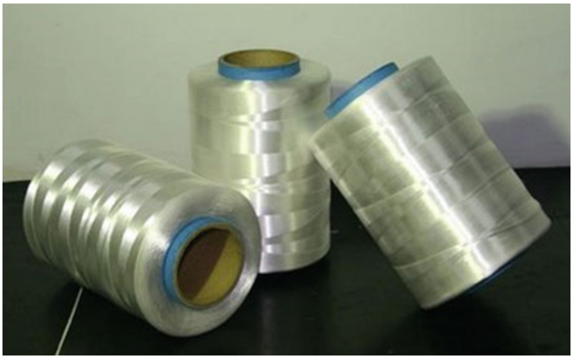

**Fig. 2.6** Polyethylene filament

#### 2.4.8.3 Properties of Hemp Fiber

- Breathable and Light weight: Hemp fiber is light weight as compared to cotton and has better breathable properties as well.
- Water resistance: Hemp fiber is partially hydrophobic in nature; it can be used in harsh weather.
- UV resistant: Hemp fiber is a good UV resistant in nature as compared to cotton and silk fiber, it maintained fresher for long time in sun light.
- Mold Resistant: Hemp fiber shows good resistant against bacteria, mold, different chemicals and good abrasion resistance.
- Tensile strength: Hemp is considered one of the strongest natural fiber, it shows four times higher strength as compared to cotton and wool.
- Water efficient: Hemp uses half of the water required for cotton crop, which means in the current scenario, hemp is the best considered fiber due to less water consumption crop.
- Hemp fiber harvesting time is about 3–4 months which shows we can grow it three times a year.
- Hemp fiber is the organic growth fiber, it required very less quantity of chemicals for growth.

#### 2.4.8.4 Applications of Hemp Fiber

Hemp is used to make a range of industrial and commercial products, including shoes, food, paper, bioplastics, clothing, ropes, textiles, biofuel, and insulation.

## 2.5 Man-Made Fibers in Technical Textiles

Fibers manufactured artificially through chemicals are called man-made fibers. The usage of man-made fibers in technical textiles are about 70% of the total fibers used in technical textiles. Fibers used in technical textiles are given below.

- Polyethylene
- Polyester
- Nylon
- Carbon
- Polypropylene
- Glass fiber
- Viscose fiber
- Acrylic fiber
- Protein fiber
- Metal fiber.

### *2.5.1 Polyethylene*

#### 2.5.1.1 Introduction

Polyethylene fiber made from the many number of ethylene monomers join with each other to form polyethylene polymer. Polyethylene fibers were manufactured through the melt spinning technique, its production started during the Second World War. In 1933 English company ICI first polymerized the ethylene monomers. Polyethylene is a stiff, hard, and strong fiber, dimensionally stable with lower moisture regain. Polyethylene fibers act as gas barriers and show good resistance against oils, greases, and acids. Polyethylene fiber is colorless and transparent in nature, but in the case of increasing thickness, it becomes opaque and off-white. It shows good resistance against ultraviolet light and it has self-extinguishing properties. Different methods are used for the polymerization of ethane to produce ethylene fiber. Some of them are ion polymerization, cationic polymerization, anionic addition polymerization, and radical polymerization. From each method the developed polyethylene gives different properties, it depends on the mechanical weight, branching, and crystal group. Some important properties are given below (Fig. 2.7).

#### 2.5.1.2 Physical Properties of Polyethylene

- Excellent resistance against the ultraviolet region of light
- Excellent resistance against chemicals like acids, oils, and grease
- Excellent resistance against the electrical flow
- Moisture regain of polyethylene is almost zero

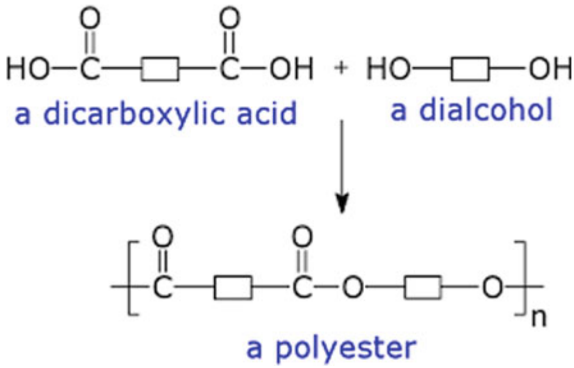


**Fig. 2.7** Polyester fiber reaction and product

- The abrasion resistance of polyethylene fiber is very good
- The specific gravity of polyethylene is 0.92
- Polyethylene fiber has good specific modulus and specific strength. The tenacity of polyethylene is 1.0–1.5 g per Denier
- Polyethylene elongation at break percentage is 45–50%
- Tensile Strength of polyethylene in psi is 15,000
- Softening temperature range is: 85–90°.

#### 2.5.1.3 Application of Polyethylene

- Polyethylene fiber is used in medical textiles,
- marine ropes and cables are made from polyethylene,
- sailcloth is made from polyethylene due to its higher strength and low moisture regain,
- it is also used in composites as reinforcement in a pressure vessel and boat hulls, impact shields, sports equipment,
- fish netting are also made from polyethylene fiber,
- it is used in concrete reinforcement,
- it is used in protective textiles,
- low dielectric polyethylene fibers are used in the protective cover of radar,
- can be used as a lining material of a pond which collects evaporation of water and containment from industrial plants,
- polyethylene is in technical textile branch geotextile applications.

#### 2.5.1.4 Polyethylene Manufacturers

Polyethylene leading manufacturers are Kemex BV, Fibra S/A, Reliance industries, private limited and fiber group, etc.

## 2.6 Polyester

### 2.6.1 Introduction

According to the US federal trade commission the fiber in which long-chain synthetic polymer contains at least 85% ester by weight is called polyester fiber. US company Du Pont firstly developed polyester in 1946 under the trade name of terylene. Addition polymerization of a dicarboxylic acid and dialcohol monomers join to form a polyester polymer. Mostly the polyester fiber was developed from terephthalic acid and ethylene glycol, which is also commonly known as polyethylene terephthalate (PET). The production and consumption of polyester fibers are more than 50% of the total fibers synthetic and natural in the world, its due unique properties like a low price, high strength, recyclability, and versatility. Melt spinning technique is used for the manufacturing of polyester filaments, for blending with natural fibers, it can be cut into desired cut length. Polyester fiber is also used in the blended form with natural fibers to achieve desired properties like high strength from polyester part and good moisture absorption and comfort from the cotton part in the blended yarn.

### 2.6.2 Polyester Fiber Properties

- Polyester fiber shows good wrinkle resistance.
- Moisture regain of polyester fiber is 0.4%, it also has poor wicking property.
- The specific gravity of polyester is about 1.22–1.38 depending on the type of polyester, polyester fiber density is between rayon and polyamide.
- Polyester fiber melts over the range of 250–300 near to polyamide fibers.in flame, it shrinks and melts leaving hard residual.
- Mechanical properties of the polyester fiber depend on the drawing of fiber, as the alignment of molecular chains increases, the tensile strength and modulus also increase.
- Showing good resistance to oxidizing agents.
- Azeotrophe esterification in polyester fiber is possible.
- Alcoholic transesterification in polyester is possible.
- Heat setting of polyester can improve the shape and wrinkle resistance more.
- Cross-linking and polymerization in polyester fiber is possible through exothermic reactions.

- **Application of Polyester**
  Polyester fiber is widely used in apparels and upholstery in both woven and knitted fabric structures. It is used in pants, jackets, shirts, sock, blankets, bedroom textiles, cushions, carpets backing, as insulator in pillows, comforters, industrial threads and ropes as a reinforcement in tires. In protective textile the application of polyester are safety belts, tapes, work wears, conveyor belt fabrics. In jet

engines polyester is used as abradable seal. It is blended with natural fibers to give strength and used in apparels. It is useful in holograms, tarpaulin, in filters, and liquid crystal displays. It can be used as an insulator in auto-body fillers, casting materials, and fiberglass laminating resins (because of thermosetting property). Useful in finishing of high-quality wooden products.

- **Polyester Manufacturers**
  The leading manufacturers of polyester are Du Pont, Reliance industries, Futura polyester, Indo Rama, Celanese AG, etc.

## 2.7 Nylon Fiber

### *2.7.1 Introduction*

According to the US federal trade commission, Polyamide fiber is the synthetic aliphatic or semi-aromatic polymer, in which the number of the amide linkages must be at least 85% of the total polymer chain weight. These amide linkages must be directly attached to two aliphatic groups. Du Pont firstly developed Nylon 6,6 in 1935. Nylon is not the original generic term used for polyamide fibers, it the Trade name of Du Pont developed polyamide fiber, which was developed through a condensation reaction of hexamethylene diamine—adipic acid. In polyamide fiber the other important fiber is Nylon 6. It is also called polycaprolactam. It was developed by Paul schlack alternative to Nylon 6,6 of Du Pont. Nylon fiber is stronger and more elastic than polyester fiber. Another important characteristic of nylon is good abrasion resistance, easy to wash, excellent toughness, and available in different colors. Fabric developed from nylon filaments are lightweight, soft smooth and having resilience.

### *2.7.2 Nylon Fiber Properties*

Nylon is a strong and elastic fiber; its washing is easy, does not require any special arrangement for laundering. Nylon dries quickly, retains its shape, it is resilient in nature, cannot easily change its shape, a good resistant to ultraviolet and heat. Nylon fiber is resistant to most of common chemicals. Moisture regain of nylon is 4%. Nylon fiber shows good fatigue resistance.

| | |
|---|---|
| Tensile strength (tenacity) of Nylon fiber | Excellent |
| Abrasion resistance property | Excellent |
| Absorbency of Nylon | Fair |
| Static resistance property | Fair-poor |
| Heat resistance of nylon fiber | Fair |

(continued)

(continued)

| | |
|---|---|
| Wrinkle resistance of fiber | Good–Excellent |
| Resistance to Sunlight of nylon fiber | Poor |
| Nylon fiber Elasticity | Excellent |
| Flame resistance of fiber | Does not burn |
| Resilience property | Excellent |

### *2.7.3 Application of Nylon Fiber*

Nylon fiber is used in lady's hosiery. Nylon is also used in dress, socks, swimmer suits, activewear, bedspreads, shorts, windbreakers, and draperies. Nylon is also used in umbrellas, luggage, flak vests, combat uniform, life jackets, and parachutes fabrics. Bridal veils are also manufactured from nylon fibers. In car tires and belts nylon is also used. Wool is replaced by nylon in carpets manufacturing. Nylon fiber through air-texturing technique adds bulkiness to make it suitable for floor covering. Nylon 6/6 is used in nuts, rollers, bolts, gears, electrical connectors, cams, bearings, kitchen utensils, coil formers, car fuel tanks, combs, and power tool housings.

### *2.7.4 Nylon Manufacturers*

Leading manufacturers of Nylon fiber are Altex Limited, Domatex Pvt Ltd, American falcon, Alpha Flock Pvt Ltd.

## 2.8 Carbon Fiber

### *2.8.1 Introduction*

The fiber consists of at least 92% by mass carbon atom in the chain is called carbon fiber, this term is used for filaments, roving, and yarns as well. In carbon fiber structure, there is the regular arrangement of graphite crystalline. This well-organized crystalline arrangement gives it unique properties like high tensile strength, high stiffness, excellent chemical resistance, lightweight, thermal expansion are low in carbon fiber, withstand its properties at high temperature as well. Carbon fiber can be classified into many categories based on properties and on the basis of origin as well [21, 22].

**Table 2.3** Properties comparison of different Carbon grades

| | |
|---|---|
| Ultra-High Modulus (UHM) | Modulus >450 GPa of carbon fiber |
| High Modulus (HM) | Modulus ranges between 350 and 450 GPa |
| Intermediate Modulus Carbon fiber (IM) | 200–350 GPa modulus |
| Low Modulus high tensile carbon fiber | Modulus <100 GPa and tensile strength >3.0 GPa |
| Super High Tensile carbon (SHT) | 4.5 GPa tensile strength of carbon |

#### 2.8.1.1 Classification Based on Properties

Classification based on precursor material:

PAN-based carbon fiber, Mesophase pitch-based, Gas Phase carbon fiber, Rayon-based, Pitch-based, isotropic-based (Table 2.3).

#### 2.8.1.2 Properties of Carbon Fiber

Carbon fiber properties are given below [23].

- High tensile strength 10 times stronger than steel
- Hgh Specific toughness
- Carbon fiber is five times lighter than steel at equal strength
- Carbon fiber shows excellent dimensional stability
- Increase or decrease in temperature cannot affect its dimensions
- Excellent abrasion resistance
- Excellent fatigue and vibration resistance
- Bological inert in nature carbon fiber
- Carbon fiber is a good corrosion and chemical resistant fiber
- Self-lubrication and high damping properties of carbon fiber
- Carbon fiber has good electrical conductivity
- Excellent electromagnetic properties.

**Application of Carbon Fiber**

Due to excellent properties carbon fiber application is widespread. It is used in high tech applications like aerospace, defense applications, civil engineering in the medical field, in automobile industry, in communication, etc. [24].

**Carbon Fiber Manufacturers**

The main manufacturers in the world are Acordis, CIXI aiflon, Ocean power fiber, and East Midlands Ltd.

## 2.9 Polypropylene

### *2.9.1 Introduction*

Polypropylene is the thermoplastic stereoregular polymer. In 1970s the polypropylene was first introduced to the textile world. Its synthetic fibers, developed from the propylene monomers. The linear structure chemical formula is $CnH_2n$. Polypropylene polymer is the by-product of petroleum process of oil refinery. It's the fourth rapidly growing synthetic fibers after, polyester fiber, nylon fiber, and acrylic. Its major application is in industrial products applications. The linear structure of polypropylene is shown in below figure [25] (Fig. 2.8).

**Properties of Polypropylene Fiber**:

The properties of polypropylene fiber are given below [26].

- Polypropylene fiber is thermoplastic in nature
- It has good strength
- PP fiber has good environmental resistance
- Low density, hence lightweight
- Good toughness property of PP fiber
- Ability to be remolded in different shapes due to thermoplastic nature (Table 2.4).

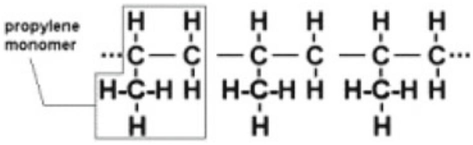


**Fig. 2.8** Linear Structure of Polypropylene

**Table 2.4** Polypropylene fiber properties

| | |
|---|---|
| Tensile strength (gf/den) | 3.5–5.5 |
| Elongation (%) | 40–100 |
| Abrasion resistance | Good |
| Moisture absorption (%) | 0–0.05 |
| Softening point (°C) | 140 |
| Melting point (°C) | 165 |
| Chemical resistance | Generally excellent |
| Relative density | 0.91 |
| Thermal conductivity | 6.0 (with air as 1.0) |
| Electric insulation | Excellent |
| Resistance to mildew, moth | Excellent |

### *2.9.2 Application of Polypropylene Fiber*

Polypropylene fibers are used as nonwoven in sanitary products, diapers, the filtration of air, liquids, and gas polypropylene fibers. Domestic water filters and filters used in air conditions for air filtration are made from polypropylene fiber. Polypropylene nonwoven sheet is used for oil absorbers in oil spills due to its oleophilic nature. In protective clothing against warm weather polypropylene fabric is used, to transports the sweat from the skin to the outer atmosphere, and keep the body dry. Pelvic and hernia tissues prolapse mending operation to protect from a new hernia in the body in the same position. Ropes, packing socks, and twines are also made from polypropylene which may be used in fertilizer, food industries, and in agricultural sectors. Polypropylene fiber may be used as bale wrapping. In civil construction, high modulus polypropylene is used as reinforcement. Polypropylene fabrics can be used as a backing material in furniture, as wall covering. Tarpaulins, luggagees, and tables clothes are made from polypropylene fibers. Polypropylene filaments are used in sports tech. In the form of nonwoven, it is used in face masks.

**Polypropylene Fiber Manufacturers**

The industries manufactured the PP fiber is PFE Engineering Ltd., International Polymers Inc, Dam River, Trevos Kostaloy Sro.

## 2.10 Glass Fiber

### *2.10.1 Introduction*

According to the definition of ASTM (American Society for Testing and Materials) Glass fiber is an inorganic fiber and non-crystalline fiber. Totally opposite to the basic definition of high-performance fiber, it has three-dimensional isotropic non-crystalline structure. Glass fiber drawing is an ancient art, in 1700s scientist named Reaumur first developed glass fiber that can be spun into yarn and developed woven fabric from that spun yarn. The first dress was developed by Edward Drummond from glass in 1893, glass fiber dress first time was used by actress Georgia Cayyan, and it was also used in the funeral coffin of Napoleon. From 1936 the commercial production of glass fiber was started (Fig. 2.9).

**Fig. 2.9** Bundle of glass fiber

### *2.10.2 Glass Fiber Types*

**Properties of Glass Fiber**

Glass fiber has versatile properties some of them are given below.

- Glass fiber has high tenacity
- Nonflammable fiber
- Moisture cannot affect its properties
- Glass fiber shows good electrical insulation
- Glass fiber shows better chemical resistance
- Relatively poor fatigue resistance
- Good strength properties in various conditions
- Low-cost fiber
- Dimensional stability: it is dimensionally stable fiber, variations in the temperature and moisture cannot affect its dimensions (Table 2.5).

**Application of Glass Fiber**

- It is used in composites as reinforcement.
- In storage tanks manufacturing glass fiber laminates are used.
- Glass fiber in woven structure can be used in production of composite panels, surfboards, etc.
- Due to its excellent thermal insulation it is used in applications where thermal insulation is required.

**Table 2.5** Different types of glass fibers

| | |
|---|---|
| A-glass fiber | It is alkalis resistant glass fiber, as per consumption it is equal to windows glass |
| C-glass fiber | Glass fiber which shows better chemical resistance is called C-glass fiber |
| E-glass fiber | Glass fiber which shows better chemical resistance and good electrical insulation are called E-glass fiber |
| AE-glass fiber | The glass fiber which shows better resistance against alkalis |
| S-glass fiber | This type of glass fiber shows better mechanical properties as compared to other glass fiber types |

**Manufacturers of Glass Fiber**

The manufacturers of glass fibers are Central Glass Co. Ltd., Snoma Science and Technology Co. Ltd., Nippon Electric Elass Co. Ltd., Saint-Gobain Vertex.

## 2.11 Viscose Fiber

### *2.11.1 Introduction*

According to the federal trade commission a fiber manufactured from regenerated cellulose in which the substitute does not replace more than 15% of hydrogen from hydroxyl groups is a regenerated fiber in which the cellulose is used as raw material, it is a less expensive fiber, its properties are just like cotton fiber.

#### 2.11.1.1 Properties of Viscose Fiber

- Viscose fiber has an aesthetic feel and drape just like silk.
- It retains its colors.
- Its properties are just like cotton and other cellulosic fibers.
- Moisture regain is higher than cotton 13% M.R.
- Comfortable fabric developed from viscose fiber.
- Good air permeability of viscose fabric.
- Dyeability of viscose is easy.
- Good resistance against static charges.
- Moderate strength in dry state and moderate abrasion resistance.

#### 2.11.1.2 Viscose Fibers Applications

- Viscose are used in apparel, industrial products like tire cord, medical field, upholstery, and bedspreads (Fig. 2.10).


**Fig. 2.10** Examples of viscose fiber products

#### 2.11.1.3 Manufacturers of Viscose Fiber

The manufacturer of viscose fibers are Denish Fabrics, Birla Viscose, Lenzing Technik, Celanese Acetate.

## 2.12 Novel Fibers

Novel fibers are developed from special techniques. Some of the novel fiber are nanofiber, auxetic fibers, conductive fibers.

### *2.12.1 Nanofibers*

#### 2.12.1.1 Introduction

Nanotechnology is defined as the study of matters, function, and phenomena which have at least one or all dimensions <100 nm. Nanotechnology is an advanced technology, which will significantly affect the advancement of the entire textile world, as well as the products, types of its application. Nanotechnology will play a vital role in the development of the textile industry cleaner, energy-saving and efficient industry. With the help of nanotechnology multifunctional textile can be developed such as antibacterial, protection against mold, water repellent products, which can be used in camouflage and sensors, etc. The market of nanofibers are about 176 US million dollars in 2012 and it grows to 825 million US dollars in 2017. It is expected that this market will reach 4.3 billion US dollars in 2023. Its market will increase gradually every year [27]. Nanofibers are the fibers whose diameter is <100 nm are called nanofibers. Nanofibers are developed through different techniques. The methods used for the development of nanofibers are self-assembly, bicomponent extrusion, phase separation, melt blowing, template synthesis, centrifugal spinning, drawing and electrospinning [28].

### *2.12.2 Properties of Nanofibers*

Nanofibers have unique chemical and physical properties, heat, and electrical conductivity, strength, elongation. Many other chemicals and properties may be different from the same materials in bulk size. Nanofibers have high surface to volume ratio, low density, improve mechanical properties, high surface energy.

#### 2.12.2.1 Application of Nanofibers

Due to unique properties, area of application of nanofibers are widespread. It can used in filtration of air, water, and oil separation, in energy conservation used in batteries, medical textiles, self-cleaning textiles, electronics field, smart textiles, sports tech, etc.

## 2.13 Auxetic Fibers

### *2.13.1 Introduction*

Poisson's ratio is defined as the ratio between strain of transverse and strain of longitudinal direction under loading. Conventional materials that have a positive Poisson ratio around 0 to +0.5 or $-1 < \nu \leq 0.5$ which shows that these materials contracts or becomes thinner when stretched because interatomic bonds realign themselves with deformation as shown in Fig. 2.11.

Auxetic stuffs are the materials that expand laterally when stretched and get thinner laterally on compression unlike conventional materials. Auxetic effect exists naturally in some minerals and animals' skin. Auxetic effect is produced synthetically to use its unique properties for smart application [29, 30]. Auxetic materials are distinguished due to its negative poison ration.

### 2.13.2 Properties of Auxetic Materials

These materials show better mechanical properties like:

1. Fracture toughness
2. Energy absorption
3. Good indentation resistance
4. High transverse shear modulus

Fracture toughness is the separation of an object into two or more pieces when stress is applied on the material. The ability of a material that has a crack to prevent fracture of the object is known as fracture toughness. Fracture behavior of conventional and auxetic foams under tension is brittle like as both show failure suddenly without showing necking. In the cells of foams crack extend in distinct ways continuously. When a high force is applied at a crack tip in the cell degree or walls fracture takes place and crack increases continuously. The toughness of the auxetic foams as compared to conventional foams is increased by 80–160% due to higher extension [29].

Auxiliary materials have better energy absorption, like ultrasound, acoustics, and dampers compared to conventional materials. The auxetic foams have 80% more vibration damping for superior energy absorption than conventional foams [31].

Auxiliary materials have a better tendency to indentation compared to conventional materials. When tension is applied to conventional or non-auxetic materials, they expand later and the thickness or density in the load direction decreases, so penetration can easily occur. In the case of auxetic material when an object is affecting the auxetic material, the auxetic material contracts in the lateral direction, the thickness, and density at the point of impact increase, therefore, the resistance to indentation increases [29].

The auxetic indentation resistance of UHMWPE increases 2.5 times as compared to the conventional UHMWPE [29, 32].

It is the relationship between the tangential force per unit area and the shear stress. Auxiliary materials have better resistance to shear stress due to torsional force

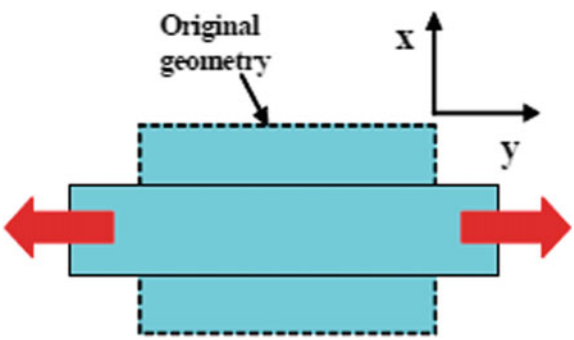


**Fig. 2.11** Poisson's ratio for conventional or non-auxetic material [29]

compared to conventional or non-auxiliary material. The relationship between the cutting module and the mass module and the Poisson relationship [31].

If the materials have a negative passion, then G (shear Modulus) will increase. And, if Poisson's ratio is −1 then the shear modulus of the material will be infinite. Shear modulus of the material.

When the poison's ratio of the material is equal −0.5 then young's modulus and shear modulus become equal to each other, so the material becomes highly compressible, but shear resistance will increase. The shear modulus of the auxetic materials is greater as compared to the bulk and young's modulus [31].

### *2.13.3 Application of Auxetic Fibers*

Auxetic fiber is used in composites as reinforcement to absorb energy to give strength to composite. It is also used in protective textiles to give protection against cut resistance, impact force, in filtration media in form of woven fabric, in medical textiles especially in drug delivery, in sports tech, ropes cord, and fishnets are also manufactured from auxetic yarn and filaments [33].

## References


1. J.E. McIntyre et al., *Textile Terms and Definitions*, 10th edn. (The Textile Institute, Manchester, 1995)
2. T.A. Perenich, Environmental issues in the textile industry. Colourage **43**(8), 19–22 (1996)
3. G. Horstmann, Environmental trends in textile production. Pakistan Text. J. **45**(2), 58–62 (1996)
4. P. Taylor, T. Matsuo, Fibre materials for advanced technical textiles, 37–41, May 2013 (2008)
5. L. Norgaard, Green' cotton—lifecycle assessment in textiles, in *Niches in the World of Textiles, Proceedings Textile Institute 77th World Conference* (1996), pp. 169–175
6. M. Kralik, Environmental influences decisive for manufacture and application of textile auxiliaries. Vlakna a Text. **2**(2), 55–60 (1995)
7. D. Franke, C. Northeim, M. Black, Furnishings and the indoor environment. J. Text. **85**(4), 496–504 (2014)
8. AR Horrocks, SC Anand, Handbook of edited by AR Horrocks, SC Anand, 1st edn. (Woodhead Publishing Ltd and CRC Press LLC, Cambridge, 2000)
9. WS Perkins, The transition toward 'green' management. Am. Text. Int. **25**(5), 62–63 (1996)
10. J Thampi, M. Jayesh R Paul, Eco-friendly textile processing—a global challenge. extile Dye. Print **26**(16), 17–20 (1996)
11. A. Laborel-Préneron, J.E. Aubert, C. Magniont, C. Tribout, A. Bertron, Plant aggregates and fibers in earth construction materials: a review. Constr. Build. Mater. **111**, 719–734 (2016)
12. A. Korjenic, J. Zach, J. Hroudová, The use of insulating materials based on natural fibers in combination with plant facades in building constructions. Energy Build. **116**, 45–58 (2016)
13. A.K. Arshad, S. Mansor, E. Shaffie, W. Hashim, Jurnal Teknologi Performance of Stone Mastic **2**, 99–103, July 2016
14. M.H. Shatil, Flax Fiber|Chemical Composition|Physical Properties and Chemical Properties|Uses and Application of Flax Fiber|Textile Study Center, Textile Study Center (2018)
15. B.B. Kalita, N. Gogoi, S. Kalita, Properties of ramie and its blends. Int. J. Eng. Res. Gen. Sci. **1**(2), 1–6 (2013)

16. A.C. Chakravarty, S.K. Sen, P.C. Dasgupta, Studies on Ramie fiber, the effect of gum content on the physical properties of Ramie fiber. J. Text. Assoc. **33**, 73, 79 (1991)
17. A.L.L. Sara, J. Kadolph, *Textiles*, 9th edn. (Prentice Hall, Upper Saddle River, NJ, 2001)
18. N. Lu, R.H. Swan, I. Ferguson, Composition, structure, and mechanical properties of hemp fiber reinforced composite with recycled high-density polyethylene matrix. J. Compos. Mater. **46**(16), 1915–1924 (2012)
19. N.N. Mahapatra, Extraction, processing, properties and use of hemp fiber. Textile Today (2018), https://www.textiletoday.com.bd/extraction-processing-properties-and-use-of-hemp-fiber/
20. N.P.G. Suardana, Y. Piao, J.K. Lim, Mechanical properties of HEMP fibers and HEMP/PP composites: effects of chemical surface treatment. Mater. Phys. Mech. **11**(1), 1–8 (2011)
21. P.J. Goodhew, A.J. Clarke, J.E. Bailey, A review of the fabrication and properties of carbon fibres. Mater. Sci. Eng. **17**(1), 3–30 (1975)
22. D. Schawaller, B. Clauß, M.R. Buchmeiser, Ceramic filament fibers—a review. Macromol. Mater. Eng. **297**(6), 502–522 (2012)
23. E. Frank, F. Hermanutz, M.R. Buchmeiser, Carbon fibers: precursors, manufacturing, and properties. Macromol. Mater. Eng. **297**(6), 493–501 (2012)
24. X. Huang, Fabrication and properties of carbon fibers. Materials (Basel) **2**(4), 2369–2403 (2009)
25. S.K. Singh, Polypropylene fiber reinforced concrete: an overview. NBMCW (2011)
26. Polypropylne fiber properties, http://syntechfibres.com/polypropylene/properties-of-polypropylen-fibres/
27. BBC, Global markets and technologies for nanofibers (2019)
28. A.A. Almetwally, M. El-Sakhawy, M.H. Elshakankery, M.H. Kasem, Technology of nanofibers: production techniques and properties—critical review. J. Text. Assoc. **78**(1), 5–14 (2017)
29. Z. Wang, H. Hu (2016) Auxetic materials and their potential applications in textiles. Text. Res. J. **84**(15) (2016)
30. D. Hull, T.W. Clyne, *An Introduction to Composite Materials* (Cambridge University Press, 1996)
31. Y. Liu, H. Hu, A review on auxetic structures and polymeric materials. Sci. Res. essays **5**(10), 1052–1063 (2010)
32. R.S. Lakes, R. Witt, Making and characterizing negative Poisson's ratio materials. Int. J. Mech. Eng. Educ. **30**(1), 50–58 (2002)
33. P. Stott, R. Mitchell, K.L. Alderson, A. Alderson, Auxetic materials—applications. Mater. World **8**, 12–14 (2000)