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Sheraz Ahmad
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Fibers for Technical Textiles

Springer

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Fibers for Technical Textiles

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Preface

Textile products have become an integral part of our daily life. Unlike past, when the textile products were only used for wearing, these products are now being used in various applications including very high-end application. It has only been possible because of the development and use of advanced and engineered materials. The use of these materials depends upon the requirements of the final product. Presently, the intensive research in textiles has opened new horizons which require very high technical specifications.

The textile fibers, being the basic building block, have great importance. The characteristics of a textile product depend not only on the intrinsic properties of the selected raw material but also on the subsequent processes involved in its manufacturing also. Technical textile products are very demanding in terms of performance properties. Therefore, it is impossible to select the right raw material for a certain application without sufficient knowledge of raw material properties (physical and chemical). This book will facilitate the readers, at every step of the product development, for the right choice of raw material.

The global increase in share of technical textiles imparted pressure on quality of production and performance.

Technical textile products are primarily used for their functional properties whereas conventional textiles are used for the aesthetic and furnishing purpose. In comparison to approximately 700 billion USD market of conventional textiles, which accounts for 78% of the total market, the value of the technical textile market is about 200 billion USD. Although the market share of technical textile market is many folds less than the conventional textiles right now, but it is evident that the growth of technical textile products is higher than the conventional textiles. The demand for functional products in different areas such as personal safety, lightweight replacement materials for metals, medical, health care, and industrial applications is increasing very rapidly.

Chapter 1 aims to discuss the importance of technical textiles, its market and certain standards required for technical textile products. Chapter 2 is about the different natural and man-made fibers used in the fabrication of technical textiles. Chapter 3 describes the existing classification of technical textiles, its basis, and drawback. A new classification is also proposed in this chapter. Chapter 4 has been written on fibers for protective textiles, their benefits, and their drawbacks. Chapter 5 deals with the fibers for sport textiles. The focus is on fibers for sportswear, sports equipment, and sports facilities. It also depicts the properties required for a particular application, advantages, and disadvantages. The fibers for automobiles were discussed in Chap. 6. The requirement of fibers for different automobile parts was discussed in this chapter. The Geotextile applications with respect to fibers were discussed in Chap.7. The benefits and drawbacks of different fibers were also explained. Chapter 8 has been focused on fibers for products used in agro-textiles. Chapter 9 has been written on fibers for medical textiles. It includes their important characteristics, advantages, and disadvantages. Chapter 10 deals with the fibers utilized in other sectors of technical textiles.

The contributing authors and editors have tried their best to explain the basic and advanced knowledge of fibers in this book. Keeping in view the constraint of book length, the authors and editors have tried to explain the respective topics briefly without missing the necessary details. The editors acknowledge the efforts put by all the contributing authors in their respective chapters. We hope that reader will benefit and enjoy reading this book.

Faisalabad, Pakistan

Sheraz Ahmad
Yasir Nawab
Abher Rasheed

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I set my unfeigned and meek thanks before Almighty, Who created the universe and bestowed the mankind with knowledge and wisdom to search for its secret, favored and invigorated us with the fortitude and capability to aptly complete this work, and contribute a drop to the existing ocean of scientific knowledge. The editors would like to extend their deepest gratitude to the chapter authors for their precious time to complete this book. We are also obliged to all those who provided support for the improvement of the manuscript. We would also like to express our gratitude to Springer Nature group for providing us the opportunity to contribute toward scientific knowledge.

Contents

Editors and Contributors

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Chapter 1
Introduction

Yasir Nawab and Sheraz Ahmad

Abstract Technical Textile is a dynamic and fastest growing sector, which is primarily known for performance and functional properties. In this chapter, the definition of technical textile, Scope, market share, and categories of technical textiles have been explored. The current volume market worldwide for technical textile is 193.9 billion in US dollars, and it's projected to reach $220.37 billion by 2022 at CAGR 5.89%. In terms of volume, this market is projected to reach 42.20 million metric tons by the end of 2020. The Broad areas of technical textile and their application areas, including Protech, Sportstech, Aggrotech, Clothtech, Geotech, Hometech, Indutech, MedTech, Mobiltech, Oekotech, and Packtech, are also discussed. Moreover, in this chapter, conventional fibers and high-performance fibers used in technical textiles are systematically introduced. The main principle involved in the selection of raw materials and the importance of material selection are also explored. Along with it, the Global manufacturers of technical textile products and technical textile fibers and major countries producing these fibers have also been examined. At the end, major tests for technical textile fibers, yarns, and fabric and test standards according to ASTM, AATCC, and ISO have been evaluated.

1.1 Introduction

1.1.1 Technical Textiles

Technical textiles are the textile materials and products used primarily for their technical performance and functional properties. The conventional textiles are used for the aesthetic and furnishing purpose. The main reason for usage of technical textile

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is their specific functional and physical properties. The technical textile represents various fields and has numerous applications [1].

The technical textiles gain considerable attention, the technical fibers, yarns, and fabric are being used for various technical applications apart from clothing. Various kinds of natural fibers such as flax, cotton, sisal, jute have been used since many years in the applications like tents, tarpaulins, sacking, ropes, and sailcloth. In roman times the woven fabrics and meshes were used for stabilizing marshy ground for the road building. Nowadays these are named as Geo textiles and Geo grids.

The technical textile field is very vast and diverse, hence somehow difficult to define. Generally, it comprises of the largest segment of conventional and domestic textile industry's output. Now a day almost 45% of woven, knitted, and nonwoven fabric are used in technical textile products. The biggest market of technical textiles is automotive, healthcare and construction, agriculture sector, and military applications [2].

Depending upon their endues technical textiles are categorized into 12 broad areas [3].

S. no	Category of technical textiles	Applications areas
1	Protect	Protech are the protective textiles that are used in protection against various threats such as heat and radiation for fire fighter clothing, molten metals for welders, bulletproof jackets for army and police officers, and chemical materials for labors working in petrochemical. They also provide protection against bacterial and blood pollution in hospitals. The protective textiles are made with the help of specialty fibers such as high tenacity Polyethylene terephthalate (PET) or polypropylene (PP), Aramids, Ultra-High Molecular Weight Polyethylene (UHMWPE)
2	Sportstech	Sportech are the sports textiles used mainly for making sportswear, including sports shoes and other sports accessories. Increasing interest in active sports and outdoor leisure activities such as flying and sailing sports, climbing, and cycling has led to immense growth in the consumption of textile materials related to sport goods and equipment
3	Packtech	Packtech are the packaging textiles used for bags, packaging sacks, Flexible Intermediate Bulk Carriers (FIBC) and wrappings for textile bales and carpets, durable papers, tea bags, and other food and industrial product wrappings
4	Oekotech	Oekotech are the environmental textiles used in environmental protection applications, such as floor sealing, erosion protection, air cleaning, prevention of water pollution, water cleaning, waste treatment/recycling, depositing area construction, product extraction, and domestic water sewerage plants

(continued)

(continued)

S. no	Category of technical textiles	Applications areas
5	Mobiltech	Mobiltech is used in the transportation industry for the construction of vehicles such as automobiles, railways, and ships. Examples of Mobiltech include seat covers, seat belts, nonwovens for cabin air filtration, airbags, parachutes, inflatable boats, air balloons, truck covers, and restraints which are significant textile end uses in the transportation sector
6	Medtech	Medtech includes all textile structures that are designed and manufactured for a medical application. They are used in health care and hygiene applications in both consumer and medical markets. They are generally used in bandages and sutures that are used for stitching the wounds
7	Indutech	Indutech are the industrial textiles used in different industries for functions such as separation and filtration, transportation of materials, and serving as substrates for abrasive sheets and other coated products. They range from lightweight nonwoven filters, to knitted nets and brushes, to heavyweight coated conveyor belts
8	Hometech	Hometech is used in manufacturing for many home furnishing fabrics including carpet backings, curtains, and wall coverings. Much of Hometech consists of fire-retardant fabrics
9	Geotech	Geotech are textile fabrics which can be woven, nonwoven, or knitted fabric used for a variety of purposes such as support, drainage and separation at/or below ground level, coastal engineering, earth and road construction, dam engineering, soil sealing, and drainage systems. Geotech must be thick and have good strength and durability, and low moisture absorption
10	Clothtech	Clothtech includes functional textile products that are most often invisible components in clothing and footwear products e.g., interlinings, sewing thread, insulating fiberfill, and waddings
11	Buildtech	Buildtech is used in construction and architectural applications, such as for concrete reinforcement, facade foundation, interior construction, insulation, noise prevention, visual protection, protection against sun light, and building safety. The field of textile architecture is also expanding as textile membranes are increasingly being used for roof construction. Main fabrics used are high tenacity Polyester coated with PVC
12	Agrotech	Agro-textiles, also known as Agrotech, are used in agricultural applications related to growing and harvesting of crops and animals. They are also used in forestry, horticulture, and animal and poultry rearing, including animal clothing. Agro-textiles must be strong, elongated, stiff, bio-degradable, resistant to sunlight, and nontoxic

1.1.1.1 Scope

The textile institute defined technical textiles as "The textile products and materials manufactured primarily for their functional and performance properties instead of decorative or aesthetic properties." Such a concise definition clearly leaves the considerable scope for the understanding, specifically when the increasing number of textile products are mixed for both performance and aesthetic look and provide functionality in equal measure. Such as, breathable wear application, flame retardant cloths. Though, no two published sources such as industry bodies and statistical organizations are ever seemed to adopt concisely the same method when it comes to classifying and explaining the products and applications as technical textiles [4].

The scope as well as content of functional textiles are difficult to fully define because of technological advancement, new processing and innovation and rapidly expanding market. "If the adjective 'technical or functional' is difficult to define with any precision and concisely, then so too is the scope of the term textiles" [5].

The Fig. 1.1 shows all types of products, materials as well as the process which falls within the functional textile scope. But there are certain grey regions as well as manufacturing and development of metallic wires into different products like cable-meshes, reinforcement, and screens are not considered to fall in the scope of functional textiles.

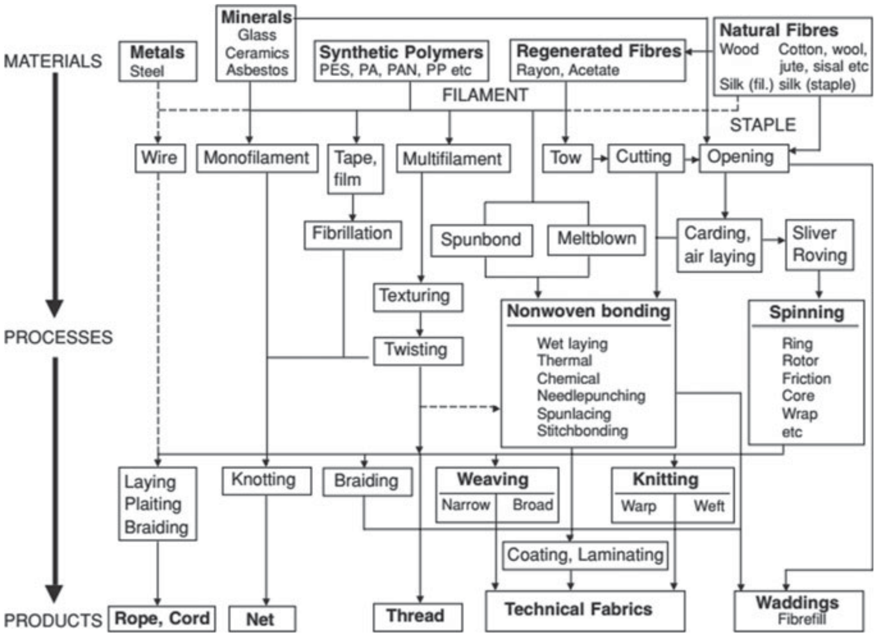


Fig. 1.1 Technical textile material, process, and product [4]

In the composite industry, the woven, knitted, nonwoven, braided reinforcements manufactured from different fibers such as glass fiber, carbon, organic polymers (aramid) fall within the premises and scope of functional textile products. Various products like loosely pulped fiber, as well as milled glass, chopped matt are not considered as a functional textile [4].

1.1.1.2 Market

The technical textile market is projected to reach US$ 193.9 billion by 2020 and US$ 220.37 billion by 2022, at a CAGR of 5.89%. In terms of volume, this market is projected to reach 42.20 Million Metric Tons by 2020 (Fig. 1.2). This illustrates that the market of technical textile is increasing significantly. This can be attributed to the increasing demand for functional products in different end-use areas such as personal safety, light weight replacement materials for metals, medical and health care, and industrial applications. The demand of technical textile worldwide is changing constantly due to technological advancement, new innovations, and superior performance. Factors such as increasing awareness on health and safety and increasing end-use applications are expected to drive the technical textile market in the future. Increasing demand from end-use industries such as healthcare, construction, clothing, packaging, sportswear and sports equipment, automotive, environmental protection, and other areas is expected to drive the overall technical textile market growth. However, the high cost of finished products affects the pricing structure of the intermediate industry, thereby restraining the growth of the market.

The forecasted share of the global technical textile market is estimated to be one fourth the global textile market sectors by 2020 as shown in Fig. 1.3.

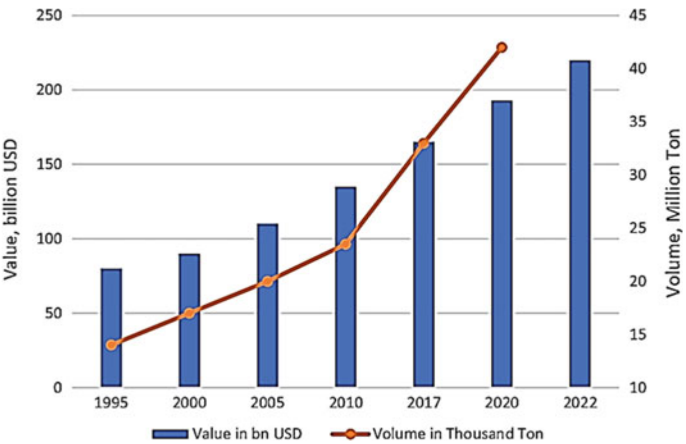


Fig. 1.2 Technical textile materials, process, and product [6]

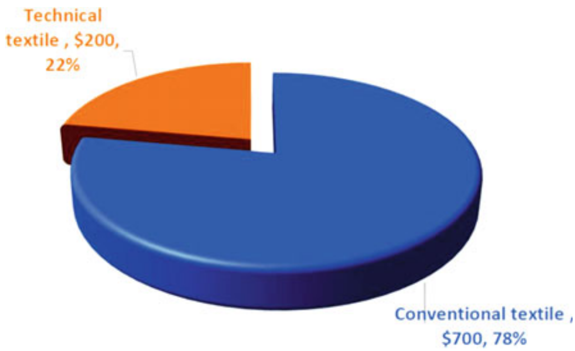


Fig. 1.3 Technical textile market share [7]

Moreover, the growth of new industries and end user requirement also lead to grow in demand of functional textiles market. Huge demands for functional textiles come from various type of industries such as sports tech, automotive, environmental protection, sports equipment and sportswear, packing industries, agriculture sector, and clothing sector [5].

There has been an increasing and smooth growth in terms of production as well as consumption of technical textile product. The technical textiles are utilized in various forms like fibers, unspun fibers, yarns, fabric, and the final product. The functional textiles are utilized in the form of unspun fibers form, yarn, and fabric, with a large part of end use of technical textiles being consumed in the form of fabric [8] (Fig. 1.4).

Among all sectors of technical textiles, the three largest contributors are Pack-tech, Aggrotech, and Clothtech. These three sectors have the largest market share in the global textiles market. Based on investment potential key contributors are, Nonwoven, Meditech, Composites, and fibers, which accounts for almost 75% of total investment in this sector. Moreover, the increasing demand of the automobile

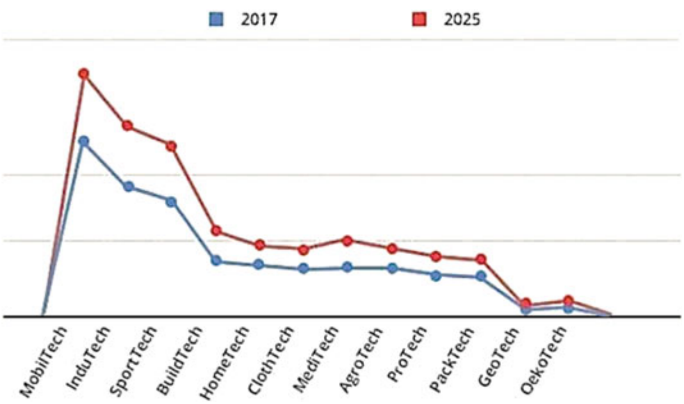


Fig. 1.4 Technical textile market volume and growth rate [9]

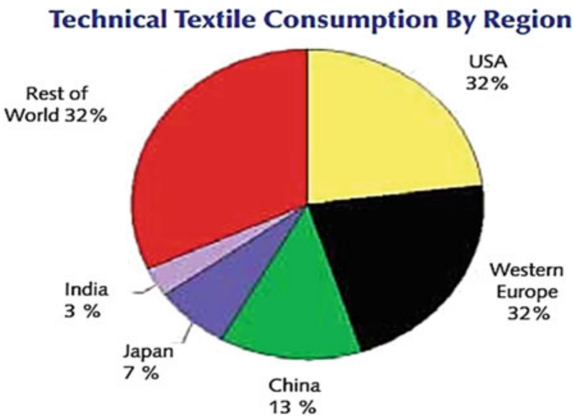


Fig. 1.5 Technical textile consumption by region [12]

industry and Geo textile is predicted to drive the Growth of Geotech and Mobiltech industry.

The developed countries like the US and EU are the global key players in the technical textile market while China and India are considered as emerging countries in this field [10]. USA is considered as a largest global market for the consumption of technical textiles products which is 23%, Europe 22%, China 13%, Japan 7%, respectively. All other countries including India, Vietnam, etc., contribute 35% of consumption of technical textiles. The Asia Pacific and Latin America is currently growing rapidly in technical textile sector. Other countries like China, Brazil, and India are expected to lead their respective regional markets and expected to grow in this sector rapidly. The growth of these countries is due to sound and effective policies, Government initiatives, and interest, spending on infrastructure play a key role in shaping and emerging the countries [11] (Fig. 1.5).

USA is the leading exporter of technical textile products, especially in Taiwan, Brazil, Korea, India. These countries are also working to enhance the market share by innovation and research development. It is predicted that in a near future these emerging countries will be competitor to the United States.

Technical textile market is growing rapidly parallel to the conventional textile sector. In technical textile the products, processes, and technologies are changing day by day, hence the market is becoming competitive as well. This innovation and demand led to expand the current market and enable to generate new ones for the technical textile sector. Many countries which are only producing conventional textiles and currently they are meeting their demands by importing from other countries are trying to shift toward technical textiles.

1.1.2 Fibers for Technical Textiles

Until the twentieth century very limited number of textile fibers were available for functions and industrial use such as cotton, flax, Sisal, and Jute. These fibers were utilized for manufacturing canvas, ropes, twines, and heavy products. These products were characterized by a heavy weight, attacked by microorganism, fungal and very low resistance to water and showed very low flame retardancy [8] (Fig. 1.6).

With the passage of time, new technical textile manufacturing units were established, for example, Dundee located in Scotland, which is the flax growing area as well as a whaling port. At that time bast fiber such as jute was used widely for sacking and packing, carpet, furniture, roofing felts, twine and other applications purpose.

Around 1900, jute industry was at a peak, but it starts to decline due to competition from other materials and cheaper, cost effective, economical import. The industries like Dundee and other industries became a central industry for the development of UK Polypropylene industry in 1960. After 1960 new polymer were developed which were superior than the conventional fibers and proved to be most suitable for technical and functional applications. Sisal was utilized and converted into the ropes, net twine. Wool and silk are versatile fibers having different industrial applications. Conventional silk is used mostly in Asia and Japan for technical and functional applications. Wool provides outstanding insulating property hence used for protective clothing and higher temperatures [14].

1.1.2.1 Conventional Fibers

The conventional fibers are modified and used for technical applications. Among various conventional fibers Viscose, PET, PP, and Polyamide can be classified as conventional fibers for technical textile application [15].

- **Viscose rayon**

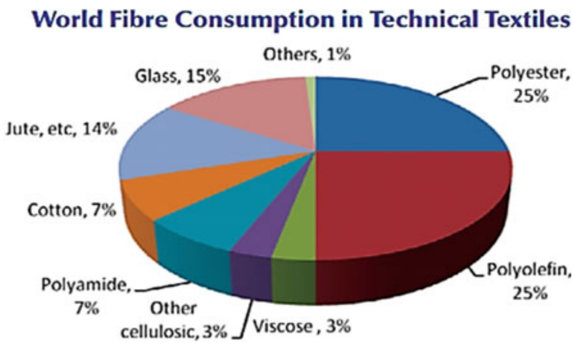


Fig. 1.6 World fiber's consumption in Technical textiles [13]

Viscose rayon was developed in 1910 and it is considered as first commercial synthetic fiber. After 1920 it was made as a reinforcement material for tires and then found its application in conveyor belts, rubber goods, drive belts, and hoses. Superior properties such as high uniformity, high modulus and tenacity and good temperature resistance enable its usage in new emerging automotive industry. Some other properties of viscose fiber are good absorbency property and easy processing of fiber by paper industry type, with wet laying techniques for its use of nonwoven products such as disposable hygiene end uses.

- **Polyamide**

Nylon or polyamide fiber was first manufactured in 1939, give high strength property as well as better abrasion resistance, good elasticity property, uniformity, and superior moisture resistance. It is widely used in climbing ropes, parachute fabrics, spinnakers sail owing to invaluable properties such as energy absorbency. Moreover, polyamide reinforced tires are being used in various countries where the quality of the road surface has been ruined and poor, as well as it is an emerging market for off road vehicles worldwide.

- **Polyester**

Polyester has superior performance properties and good in price. Its outstanding mechanical properties, heat resistance properties, resistance to light degradation, and fastness to light are outstanding. For the dyeing of polyester disperse dyes are used.

The world production of polyester has increased since 1950. Initially, it was only used for household application and with the advent of time, polyester being cost effective, finds its application as a technical textile fiber. The usage of polyester in staple and filament form is increasing rapidly for various applications. PET fiber is most widely used in fiber for technical textiles. For Airbag, tire cord, car seat applications, sail cloth, Geo textiles, fishing nets purpose, and no-woven are examples of its application product.

- **Polyolefin**

Polyolefin developed in 1960s revolutionized the technical textile sector. Polypropylene and polyethylene are mostly polyolefins used in technical applications. Major properties of polyolefin include good abrasion resistance, low density, low cost and easy processability, superior moisture resistant properties. Owing to these properties they are being used for various applications such as carpet backing purpose, for sacks, packaging purpose and in bags, furniture linings, ropes applications, and netting.

Characteristics of Polyolefins

The poor temperature resistant and hydrophobic properties have been turned into advantages in nonwoven. Firstly, used with viscose for thermal bonding purpose, polypropylene is used in hygiene due to its important role in wicking such as the cover of diaper, nappies. Polyethylene has good physical properties with normal melting temperature of 112 °C for a low density form of fiber and for high density form melting temperature reaches up to 140 °C, hence it is preferred for mostly low temperature applications.

The polypropylene fiber has superior mechanical properties than polyethylene and it can withstand temperature up to 170 °C. These polymers have lower density than water due to which they float as a net, rope on water and used in similar applications. The greatest demand of polypropylene in Geo textile is due to bulk availability, outstanding resistance to acids and environmental, and low cost [16] (Table 1.1).

Properties

Heat Resistant Fibers

There are various type of heat resistant fibers which are used as per requirement. These fibers include silica, alumina, basalt, glass fiber, PBO, tungsten fiber, carbon fiber, and P-aramid have also superior heat resistant properties. The fiber having high LOI (Limiting Oxygen Index) value shows outstanding heat resistant properties. The Table 1.2 compares the heat resistant properties of different fibers.

Table 1.1 Comparison of properties of PET, PA, and PP with Para-aramid fiber as (standard type)

Fiber material	The specific gravity	Melting point (°C)	Tg (°C)	Tensile strength (MPa)	Elongation at break (%)	LOI value (%)	Tensile modulus (GPa)
PET	1.3.7	255	71	510–691	15–41	18–22	6–11
Nylon66	1.15	250	37	350–551	18–37	20–22	3–6.5
Nylon6	1.14	221	22	450–701	20–33	20–22	2.5–3.4
PP	0.95	1162	16	411	25–61	18–21	6.4
p-Aramid	1.15	–	304	2761	3.4	30	58

Table 1.2 Properties of high heat resistance fibers

Fiber material	Melting point (°C)	Tenacity (CN/dTex)	Degradation temperature (°C)	LOI (%)
M-aramid	350	5.5	425	30
Polyamide-imide	220	2.7	450	32
Polyimide	232	3.8	470	38
Melamine	345	2.0	550	32
PPs	285	5.0	510	34
PEEK	335	7.2	480	33
PTFE	–	1.6	400	95

High-Performance Fibers

The conventional fibers discussed above account for almost 95% of all types of organic fibers used in technical textiles except glass fiber, mineral-based fiber, and metal fiber. Most of these fibers need to be converted and modified for high-tech applications by changing, tenacity, length of fiber. This includes surface modification, applying finishes or combining both types of fiber and converting into hybrid and biocomponent products. However, the high-performance start emerging after the 1980s, which have upgraded the technical textiles and increased the demand and expand market share [17].

Aramids Fiber

Firstly, aramid fibers were developed which include meta aramid and para aramid. Meta aramids are mostly used in protective clothing and similar applications while para aramid find its applications in bullet proof vest, ropes, composites, and reinforcement. Meta aramids are high-temperature resistant and para aramid are high strength and high modulus fibers.

The commercial production of p-aramid was started in 1970 and it reached almost 40,000 t per annum in 2000 at the same time meta aramid consumption was 17–18,000 t. The aramid fiber has revolutionized the technical textile industry and enhanced its market share.

Carbon Fiber

Carbon fiber is highly pure and pyrolyzed acrylic based. When the impurities are removed the carbon content increases and prevent the process of nucleation and reduce graphite crystal growth, which are responsible for the decrement of strength in these fibers. From mesophase pitch different types of carbon structures are made. In PAN fiber the graphite planes arranged themselves along the axis of the fiber instead of perpendicular as is the case with pitch base carbon fibers. Low extensibility along with high strength and modulus led to be used with epoxy resin as composites.

Carbon fiber is not only important for aerospace market, but also find its application in sports equipment and goods, industrial applications like generators, turbine blades and used as reinforcement for fuel tanks. The advancement in technology and manufacturing method reduced the cost, hence application of carbon fiber also increases.

Other High-Performance Fibers

New high-performance fibers were introduced late 1980s, which were used for technical and high-performance applications after aramids. These fibers include several types ranging from flame and heat resistant material for protective textiles like PBI, phenolic fibers, PBI, polyheterocyclic fiber, PTFE and have highest LOI values than aramid. It resists heat and chemical agents cannot attack it easily but remains rather expensive. Lenzing initially produces p. 84 and now it is produced by Inspect fibers. USA developed Polyimide that possesses high chemical and fire-resistant properties. Another fiber named as acrylic copolymer-based fiber was produced by Acordis called Index, unlike aramid fibers, it has very high resistance to ultraviolet radiations and has higher LOI value at the expense of reduced tenacity.

HMPE (need to elaborate all abbreviations) is ultra-strong high modulus polyethylene mainly used for ballistic protection and rope manufacturing. PTFE polytetrafluoroethylene is one of chemically stable, high-performance polymer fiber. PPS polyphenylene sulphide and PEEK polyethyl ether ketone are used in filtration application due to high mechanical stability and preferred for aggressive environments.

Dyneema Fiber

Dyneema is also known as ultra-high molecular weight polyethylene is strongest known fiber today with a tensile modulus of 70 GNm^2. This fiber is almost 15 time stronger as compared to steel and two times stronger than aromatic polyamides like Kevlar. Major properties include chemical inertness, low density, and high abrasion resistant. It is mostly used in low temperature application due to the low melting temperature of 150 °C and it degrades thermally at 350 °C.

Inorganic Fibers (Glass and Ceramic)

Glass fiber used for technical application for a long time. For many years it has been used as a cost-effective insulating material and reinforcement. Glass is considered as a sophisticated material having superior heat and fire resistance properties. For low performance plastic glass is used as reinforcement material and roofing material in the USA.

Now a days it is being used for different high-tech applications such as rubber reinforcement, filtration purpose, composite applications, packaging and protective clothing. The glass fiber is widely used in the automotive industry and it has replaced metal body parts, hence the market of glass reinforcement body parts is merging in the market. Ceramic fiber is used for very high-tech application, but they are restricted to limited area due to the high cost of fiber.

1.1.3 Importance of Materials Selection

The selection of right fiber depends on the end use of the product. Selection of right fiber is necessary for the performance and functionality of textiles. Generally, the performance of textile depends upon three factors:

1. Material of fiber
2. Configuration of fiber
3. The assembly structure of fiber

Furthermore, the selection of right fiber is based on cost effectiveness, reliability, desired end used properties and the ease of processability. These three structural elements should be kept in mind while choosing any fiber for certain application. Various types of fibers are used in different application for technical purpose [18].

1.1.3.1 Cost

The cost of raw material such as fiber and fabric are directly associated with the cost of the product and profitability. Hence the cost of the material is directly associated with the economy textile industry. High cost of raw material used in the fabric processing increase the total cost of product and reduce profit of the industry. In textile industry overall 70% of total cost depends on the raw material and 30% is included in processing and services. From start to final product various steps are included the developers by the product and each step add cost to the product.

The technique to use for development of technical textiles includes spinning and twisting. For technical textile various types of raw material used are fiber, natural threads, chemical fibers, dyes, etc. The high cost of raw materials is impacting the overall production cost of textile industry and affect the growth of the market. For example, according to an international manufacturer (Samruk Kazyna) in November 2016, the cost of Polypropylene was USD 1028 per t and USD 1.028 per kg. According to vendor in 2018, the cost of Polypropylene reached USD 1.2–3.5 per kg. Hence, by controlling the cost of raw materials and processing, the growth and profitability can be increased [19].

1.1.3.2 Properties

Since technical textiles are mainly focused on functionality, the requirement of functional properties such as mechanical performance, fire resistance, stab resistance, ageing, filtration, antimicrobial, antistatic, etc., is common. In addition to these functional properties, the properties are conventional textiles such as esthetics, drape, comfort, etc. are also a requirement.

These properties are mainly governed by:

i. Fiber properties
ii. Textile structure
iii. Finishing/Coating, etc.

Fiber properties mainly depend on their material, chemical structure, and microstructure of fibers. Textile structure such as spinning technique, blending of materials/fibers, fabric structure (nonwoven, woven, braiding, knitting, etc.) is a major factor to define the textile's properties. For example, a woven structure is more stable mechanically than other textile structures hence preferred for applications with requirement of good mechanical properties such as tarpaulin, stab resistance, and geotextiles, etc., however, due to its porous structure, it is not preferred for very fine filters.

Several properties of technical textiles are obtained by applying finishes and coating during textile processing. Hydrophobicity, antimicrobial activity, and fire retardancy, etc., are obtained by applying chemical finishes to textiles.

1.1.3.3 End User Requirement

Mainly technical textiles are different than conventional textiles due to end user requirement. The focus here is the performance or functionality. Due to nature and end use of these textiles, the requirements of user are diverse and more as compared to conventional textiles. Keeping in view the application, sometimes the requirement of functionality is very precise and very high quality is required. For example, in life saving application such as airbag, fire fighter suits and bullet proof shield and vest, etc., the end user requirements are very precise and strict compliance is mandatory.

1.1.4 Selection of Right Fibers

1.1.4.1 International Manufacturers

Global countries producing technical textile products are Germany, U.K, Japan, USA, Korea, France, Turkey, India, and China. Top companies producing technical products are Dupont, Ahlstrom-Munksjo, Freudenberg Performance Materials, Lenzing Plastics, Low & Bonar, Koninklijke, DeRoyal industries, SRF Limited, and Swift Textile Metalizing LLC [20].

Some of the known international fiber manufactures are given in the Table 1.3 along with fiber names, brand names, major properties of fibers, and country of origin of these manufactures.

1.1.4.2 Testing

In technical textiles, the requirements of user are mainly the functionality and the testing required for a given textiles is more as compared to conventional textiles. No dedicated test methods exist for technical textiles. Keeping in view the functionality required the test methods available in ISO, ASTM, AATC, DIN, etc., are used.

The materials used in technical textile products may be in the form of fiber, yarn, fabric, or in the form of composite. The assessment of both raw materials as well as the final product is necessary for meeting the quality standards. Testing is carried out to evaluate the functionality, performance of required products. Common testing of fiber, yarn, and fabric are listed below.

Table 1.3 Some global manufactures of technical fibers

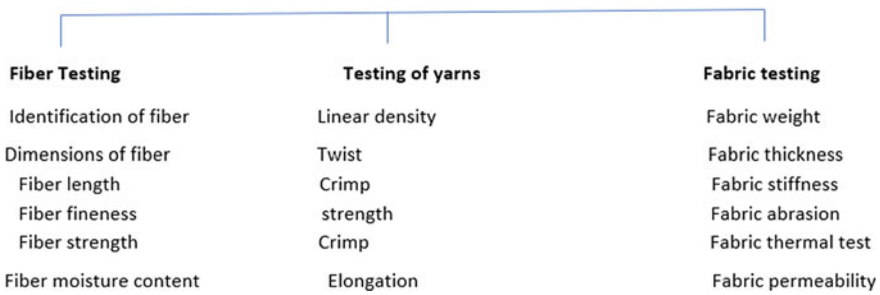
Manufacture	Fibers	Brand name	Property	Country
DMS	UHMWPE fiber	Dyneema	Cut, bullet, stab resistance	USA
Honeywell	UHMWPE fiber	Spectra	Cut, bullet, stab resistance	USA
Dupont	Aramid fiber	Kevlar	Fire, cut, bullet, stab resistance	USA
Yantai	Aramid fiber	Taparan	Fire, cut, bullet, Stab resistance	China
Hexcel	Carbon fiber	Hextow	Super mechanical properties	USA
Cytec	Carbon fiber	–	Super mechanical properties	USA
DOW AKSA	Carbon fiber	–	Super mechanical properties	Turkey
SGL group	Carbon fiber	–	Super mechanical properties	Germany
Toray	Carbon fiber	–	Super mechanical properties	Japan
Teijin	Carbon fiber	–	Super mechanical properties	Japan
Mitsubishi Rayon	Carbon fiber	–	Super mechanical properties	Japan
Owen corning	Glass fiber	NYSE	Hardness, transparency, stability, and inertness	USA
Jushi group	Glass fiber	–	Hardness, transparency, stability, and inertness	China
PPG	Glass fiber	–	Hardness, transparency, stability, and inertness	USA
Taishan	Glass fiber	Sinoma	Hardness, transparency, stability, and inertness	China
CPIC	Glass fiber	–	Hardness, transparency, stability, and inertness	Canada
Nittobo Boseki	Glass fiber	Nittobo	Hardness, transparency, stability, and inertness	Japan
Advanced glass fiber yarns	Glass fiber	–	Hardness, transparency, stability, and inertness	USA
Binani-3B	Glass fiber	–	Hardness, transparency, stability, and inertness	India
Sichuan Weibo	Glass fiber	Innofiber	Hardness, transparency, stability, and inertness	China
Jiangsu Jiuding	Glass fiber	–	Hardness, transparency, stability, and inertness	China
Lenzing	Polyester	–	Resist wrinkling, abrasion	Austria

(continued)

Table 1.3 (continued)

Manufacture	Fibers	Brand name	Property	Country
KOLON	Polyamide	–	Low creep, high tensile strength	South Korea
AKSA	PAN	–	Thermal stability, high modulus	Turkey
Dralon	PAN	–	Thermal stability, high modulus	China
Taconi	PTFE	–	High chemical resistance	China
Dow chemical company	Saran	–	Resistance to chemical such as salt, acid, alkalis etc.	USA
International fiber group	PP	–	Resist bacteria and microorganism	Sweden
Rath	Ceramic fiber	–	High-temperature resistance, good thermal stability, low thermal conductivity	Austria
Ibiden	Ceramic fiber	–	High-temperature resistance, good thermal stability, low thermal conductivity	Japan
Morgan thermal ceramics	Ceramic fiber	–	High-temperature resistance, good thermal stability, low thermal conductivity	United Kingdom
Shandong Luyang share	Ceramic fiber	–	High-temperature resistance, good thermal stability, low thermal conductivity	China

1.1.4.3 Common Tests for Technical Textile



Medical Textile Testing

Implantable Textiles

Implantable includes the replacement of damaged blood vessel and segments of the large arteries. These implantable materials are used to repair the affected part of the body. They can be used as a wound suture or used in replacement surgery. The tests should be carried out for sutures include Diameter, tensile strength, bending stiffness, surface roughness, and knot pull. Most of the implantable products are tested for Biocompatibility test [12].

Non implantable Textiles

Non implantable materials are used on the body; most of the time they have direct contact with the human skin. The test methods for the assessment of the characteristic of bandage product are yarn count, thread/10 cm surface active substances, water soluble substances, foreign matters, microorganism prior to sterility, pH, and absorbency. Surgical dressings are one of the main types of non implantable medical textile product. Health care and hygiene products are also included in the medical textile.

Geo Textile Testing’s

Various types of tests carried out on Geo textile are wide width tensile test, tension creep behavior, coefficient of friction between soil and Geo textile, and cross water Permeability testing.

Protective Textile Testing’s

Protective textile can be divided into following category according to end use, thermal protective clothing, chemical protective clothing, mechanical protective clothing, antimicrobial protective clothing, UV protective clothing, high visibility suits, radiation protective clothing, protective clothing for defense, etc. Various kinds of tests are carried out on technical textiles. Some of these are listed below (Table 1.4).

Table 1.4 Major tests and test standard required for testing of technical textiles

S. no	Property	Test standard	Equipment used
1	Static charge test	BS EN 1149-1	Conductivity tester
2	Limiting oxygen index test	IS0 4589-1, ASTM D 2863	LOI tester
3	Hydrophobicity	ASTM F22	Contact angle tester
4	Flame retardancy	ISO 6940, ASTM D 6413	Flammability tester
5	Stab resistance	NIJ standard 0115.00, ISO 13,997	Stab resistance tester
6	Cut resistance	EN388, ISO 13997	Cut resistance tester
7	Bullet resistance	NIJ. Standard 0101.06	–
8	Filtration	ISO 16890	HPLC
9	Weather resistance	M025A	Weathering tester
10	Antimicrobial activity	AATCC 100, AATCC 147	Agar diffusion
11	Impact testing	EN388	Impact tester
12	Fatigue testing	ASTM F963	Fatigue tester
13	Stretch and recovery	ASTM D3107	extensometer
14	UV/Sun protection factor test	AATCC 183	UV protection tester
15	UV resistance	ASTMD 4355	Xenon arc apparatus
16	Water resistance of fabric	ISO 811, AATCC 127	Hydrostatic head tester
17	Water repellency test (Spray method)	AATCC 22	Spray tester
18	Protective clothing for cold protection	EN342	Thermal manikin
19	Chemicals protection	EN 465,466	–
20	Electric hazard	EN 1149	Electric hazard testing machine
21	High visibility material	EN 471	–
22	Mechanical impact testing	EN 510	Impact tester
23	Radioactive contamination	EN 1073	Nuclear shield radiation
24	Thermal hazard	TS 50354	Thermal tester
25	Protective glove against mechanical risk	EN 388	CUT test machine, tensile machine
26	Protective gloves against cold	EN 511	Cold contact tester

(continued)

Table 1.4 (continued)

S. no	Property	Test standard	Equipment used
27	Body protection for sports	EN 13227	High pressure test manifold
28	Bursting strength	ISO 13938	Bursting strength tester
29	Puncture resistance testing	ASTMD 4833	Compression testing machine
30	Friction resistance	ASTMD 5321	Pendulum skid resistance tester
31	Trapezoidal tear	ASTMD 4533	Trapezoid tear tester

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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

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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:

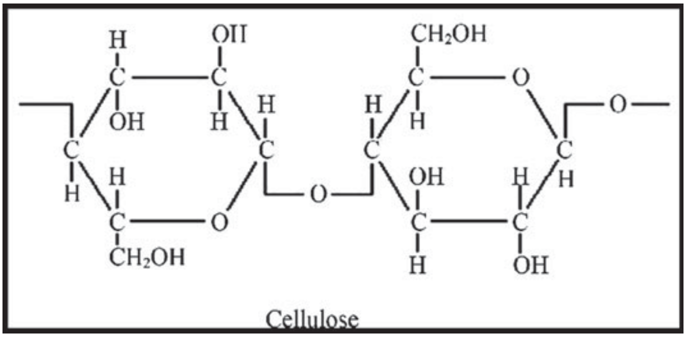

Fig. 2.1 Chemical structure of cellulose

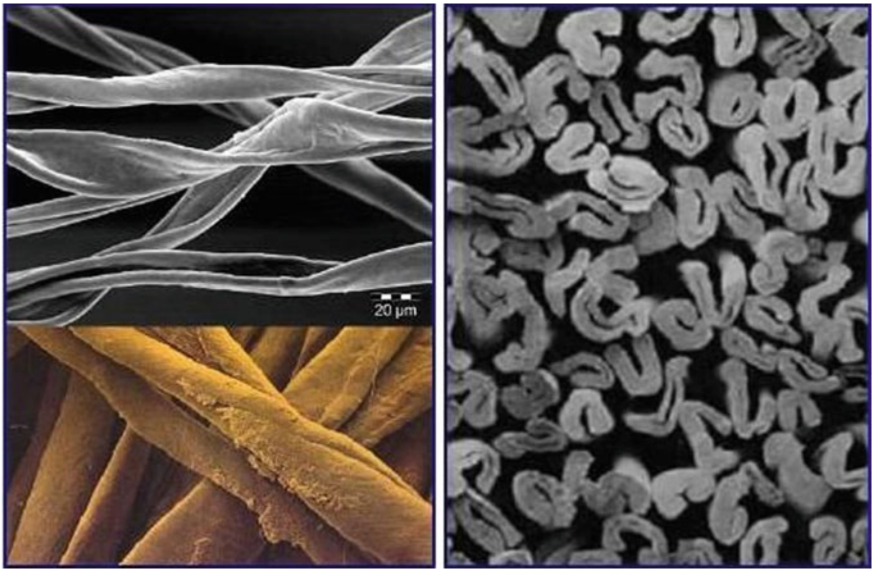

Fig. 2.2 Cross-sectional and longitudinal view of cotton fiber

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 hardwood 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.

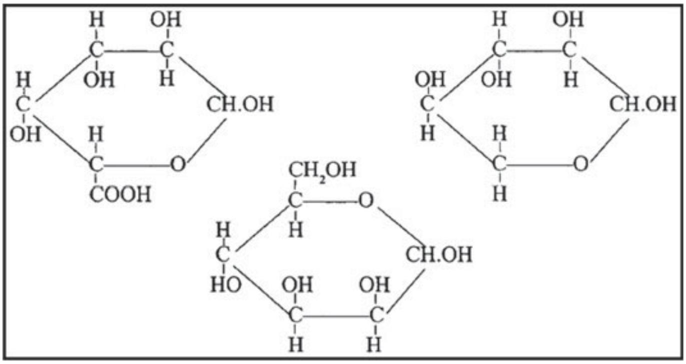

Fig. 2.3 Chemical structure of flax fiber

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**)

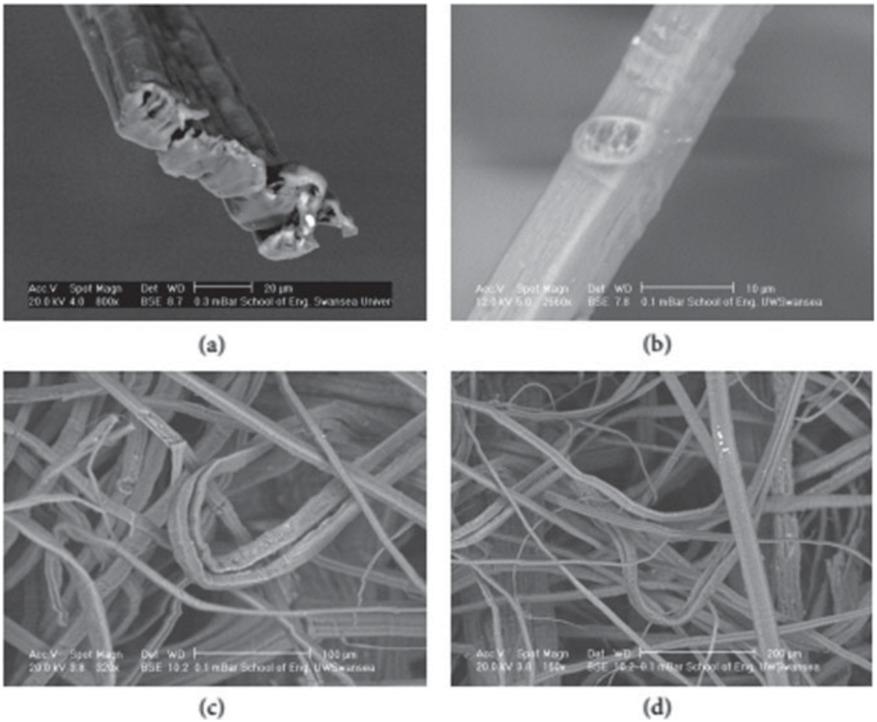

Fig. 2.5 SEM micrographs of a hemp fibre bundle, (**a**) and (**b**), and loose fibres, (**c**) and (**d**)

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].

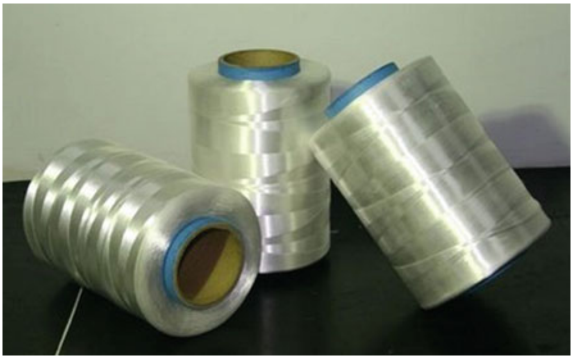

Fig. 2.6 Polyethylene filament

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

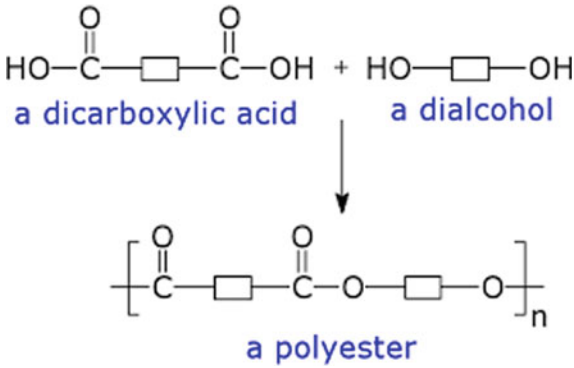

Fig. 2.7 Polyester fiber reaction and product

- 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).

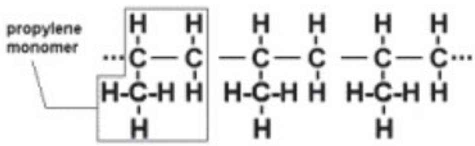

Fig. 2.8 Linear Structure of Polypropylene

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

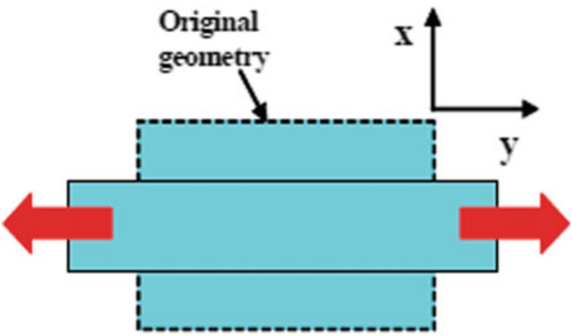

Fig. 2.11 Poisson's ratio for conventional or non-auxetic material [29]

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].

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Chapter 3
Classification of Technical Textiles

Abher Rasheed

Abstract The textile products are broadly divided into two groups, i.e., conventional textiles and technical textiles. Conventional textile products are designed, developed, or used for the common, decorative, or aesthetic applications, whereas technical textile products are those which are used in the functional applications. Technical textile products are usually classified into twelve groups, i.e., Mobiltech, Indutech, Medtech, Hometech, Clothtech, Agrotech, Buildtech, Sportech, Packtech, Geotech, Protech, and Oekotech. This classification of the technical textile products is based on the area of application. For example, products related to the medical and health care are a part of Medtech which stands for medical textiles. This classification has two drawbacks. First, several segments of the technical textile do not have clear boundaries and overlap with the other segments. For example, Oekotech overlaps with Indutech (filtration), Geotech (erosion protection), and Agrotech (water efficiency). Secondly, this classification does not help much to an entry level manufacturer of technical textiles. The reason is that each segment has a large variety of products made of diversified fibers/raw materials using divergent manufacturing techniques and equipment. In addition to that, the products have to fulfill varied testing requirements as well. Therefore, it is almost impossible to figure out a certain type of manufacturing facility to fulfill the needs of one segment. Keeping in view the very fact, technology-based classification of the technical textile products has also been proposed in this chapter.

3.1 Introduction

Textile materials or products can be divided into two parts; conventional textiles and technical textiles. The products which are used for common applications and decorative or aesthetic purposes are commonly known as conventional textiles. Conventional textiles are usually made of conventional fibers which are most of the times natural fibers. Technical Textiles, on the other hand, are defined as "materials

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and products manufactured primarily for their technical and performance properties rather than their aesthetic or decorative characteristics" [1]. The technical textile is a very vast domain. Before the advent of technical textiles, the textile products were only limited to apparel and home textiles. Now the technical textile products are everywhere around us. For example, there are protective clothing for protection against fire, cold, impact, microbes, etc. Further, textile products are being used in automobiles, industries, hospitals, agriculture construction, packing, sports, etc.

The ever-growing human needs have pushed the researchers to develop technical textile products. The technical products can not be developed without special fibers having specific properties for a certain application. Therefore, this very fact has forced the researchers to work for the development of new fibers. The development of fibers like carbon, glass, and HDPE is the result of this phenomenon.

The technical textile products are mostly made by using high-performance/technical fibers. Further, all types of fabrics (i.e., knitted, woven, nonwoven, braided, tufted, etc.) are used in technical textile products. The selection of the fabric structure is chosen based on the required properties of the product. Various types of finishes are also contributing toward the development of these products. Coating technique is very commonly used for the application of such finishes. Some of the examples of these finishes are water repellant, antistatic, antimicrobial, etc. Joining techniques other than stitching are used to make the technical products. The examples of such techniques are ultrasonic welding and thermal bonding.

The world Textile and clothing market is about US$ 750 billion [2]. The current estimate of technical textile market is about US$ 180 billion which is expected to reach US$ 250 billion in 2026 with an average 5% growth [3]. Technical textile is one of the most rapidly growing sectors of textiles.

3.2 Classification of the Technical Textiles

Techtextil, one of the largest trade exhibition of technical textiles, classify technical textile products into 12 main areas of application which are depicted in Fig. 3.1, [4].

3.2.1 Mobiltech

The textile products which are used in the transportation (automobiles, railways, ships, aircrafts, and spacecrafts) are known as mobiltech. Some of the examples of mobiltech products are parachutes, inflatable boats, air balloons, automobile covers, etc. Some of the textile products are used as a component in an automobile. These components can be classified into two, i.e., visible components and concealed components. Some of the examples of visible components are:

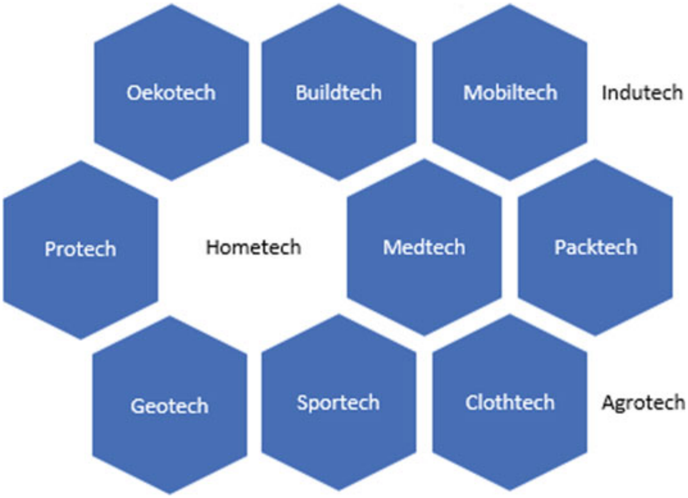

Fig. 3.1 Branches of technical textiles

- Seat covers.
- Seat belts.
- Carpet.
- Foot mats.

The concealed components may include:

- Airbags.
- Tyre cords.
- Insulation felts.

The mobiltech products are used in interior, engine, and body of the automobiles. The average weight of the mobiltech products used in the interior of an automobile is around 20 kg [5]. The mobiltech products are used for several functions which include transportation, filtration, insulation, protection, etc.

3.2.2 Indutech

Indutech stands for industrial textiles. These are the textile products which are used in the industrial/manufacturing sector. The most commonly used examples of indutch products are:

- Conveyer belts.
- Ropes.
- Filters.
- Composite materials for industrial use.

These products are usually made by using nonwoven or woven textile structures. The application areas include filtration, purification, and transportation. Filters are used for air, water, or oil filtration. Conveyer belts are used for transportation of materials. Ropes are used in shipping, ports, oil rigs, and defense areas [6]. The most commonly used fibers for indutech products are synthetic, e.g., polyester, polyamide, polypropylene, and nylon, etc.

3.2.3 Medtech

Medtech is a short form of medical textiles. These are the products used for healthcare and hygiene sectors. This domain has a wide product range. These products can be divided into two categories; wearables and non-wearables. Some examples of the wearable products are:

- Face mask.
- Diapers.
- Patient gown.
- Doctor's gown.
- Pressure garments.
- Protective suits.

Non-wearable products may include:

- Wipes.
- Bandages.
- Gauzes.
- Sutures.
- Scaffolds.
- Artificial body parts.

Medtech products are developed by using both natural (cotton, silk, wool, etc.) and synthetic (polyester, rayon, etc.) fibers. The selection of the fiber is based on the requirement of the final product. For example, natural fibers may be used for high absorbency and biodegradability whereas synthetic fibers find their use for strength and elasticity [7]. Almost all types of textile structures are used in medtech. For instance, yarn (sutures), woven structures (patient gown, doctor gown, bandages, etc.), nonwoven structures (facemask, diapers, wipes, etc.), and Knitted structure (pressure garments, etc.) are used in medtech. Some of the functions of medtech products are cleaning, absorbency, filtration, protection, etc.

3.2.4 Hometech

The technical textile products which are used inside buildings are known as hometech. It consists of household textiles and upholstery (sleeping bags, cushions, and bedding, etc.). Some examples of the hometech products are:

- Blinds.
- Floor covering.
- Wall covering.
- Cushions.
- Shower curtains.
- Towels.
- Cooking aprons.
- Oven mittens.
- Table covers.
- Bread baskets/covers.

Both natural and synthetic fibers are used in the development of these products. The end use dictates the type of fibers to be used. For example, wool may be used for insulation and cotton may be used for absorbency. Most of the products are made of woven (shower curtain, towel, etc.) or multilayer composite structures (oven mittens, etc.). Coating fabrics are very commonly used in these applications (shower curtains, table covers, etc.). These products are usually used for waterproofing, fireproofing, insulation, absorbency, protection from sun, protection from harsh weather, and leisure. Most of these products are made fire retardant to minimize the harm in case of a fire incident [8].

3.2.5 Clothtech

The textile products used to satisfy the functional requirements of apparels are called Clothtech. These are basically the components of garments or shoes which are most of the times concealed. some of the examples of Clothtech are:

- Interlining.
- Underlining.
- Velcro.
- Fasteners.
- Elastics.
- Labels.
- Sewing thread.
- Shoelaces.
- Draw cords.

The typical functions of these products include insulation (interlining), garment stability (underlining), tactile comfort (underlining), ease in wearing (Velcro, fasteners, elastic, and shoelaces, etc.), protection (drawcord), and joining sewing thread. Various types of fibers (cotton, polyester, nylon, elastane, etc.) are used to make these products. The selection of the fiber is dependent on the end use of the product. Almost all types of textile structures are used in these products. For example, the applications of yarn (sewing thread), braided (drawcord, shoelaces), nonwoven (interlining), woven (interlining, underlining, elastics, labels, etc.), and knitted (interlining) structures can be found in clothtech [9, 10].

3.2.6 Agrotech

The technical textile products used in agriculture, horticulture, fisheries, and forestry are known as Agrotech. These products are used for growing and harvesting of crops. This is a very wide domain of technical textiles. Some of the common examples of the Agrotech products are:

- Shade nets.
- Crop covers.
- Bird protection nets.
- Anti-hail nets.
- Fishing nets.

The use of Agrotech products improves the quality of crops, controls the weed, enhances and accelerates the yield. Both natural and synthetic fibers may be used in aggrotech products depending upon the requirement of the product. The common functions of these products are protection from extreme weather, protection from mosquitos, protection from birds, insulation, packing, etc. The textile structures like knitted (packing materials and nets), woven/nonwoven (mulch mats, sapling bags, shades, and ground covers), and knotted (fishing and other nets) can be used to make these products. [11]

3.2.7 Buildtech

These are the products which relate to the construction and architectural application for temporary or permanent structures. The material/structures used may be in the form of textile alone or multilayer composites reinforced with a textile material. The common examples of buildtech are:

- Hoardings and signage.
- Canopies.
- Tarpaulins.
- Shades.
- Textile reinforcements for concrete.

- Sound absorption sheets.
- Thermal insulation sheets.

The requisite properties of buildtech products are lightweight, strength, water resistance, chemical resistance, weather resistance, aging, concrete reinforcement, facade foundation, interior construction, insulation [12], noise prevention, visual protection and protection against sun light, etc.

3.2.8 Packtech

Packtech are the textile products which are used for packaging. They can be found in the packing of agriculture, industrial, and consumer products. Some of the examples of Packtech products are as follows:

- Bags/Sacks.
- FIBC (flexible intermediate bulk container).
- Tea/coffee bags.
- Courier envelops.
- Adhesive tapes.
- Electrical insulation wraps.

Conventionally natural fibers (jute, etc.) were used to make bags and sacks which are now been replaced with the synthetic fibers (polypropylene). These products are used for packing grains, vegetables, fruits, clothing, shoes, and electronic appliances, etc. The major objective of these products is to improve the shelve life of a product which is usually carried out by controlling the temperature and moisture transport of a product. The other function of such products is the easy transportation of the packed materials. Woven (bags/sacks), plastic sheets (wrapping sheets), nonwoven (tea/coffee bags), and leno nets (for packaging of fruits and vegetables) are the most commonly used structures. [13].

3.2.9 Sportech

The technical textile products used for sports and leisure like running, cycling, swimming, indoor sports, and outdoor sports are known as Sportech. Thanks to the increasing interest of people in outdoor leisure activities and sports there has been enormous growth in the consumption of sportech materials [14]. Commonly used products include:

- Climbing ropes.
- Tracksuit.
- Running shoes.
- Helmets.

- Artificial turf.
- Parachute fabrics.
- Sleeping bags.
- Swimwear.
- Football.
- Sports equipment (hockey sticks, racket, cricket balls, etc.)

Sportech contains the products for almost all kind of sports. Protection from extreme weather, protection from injury/impact, strength, water resistance, good comfort properties, stretch, and recovery are some of the functions needed in different sportech products. Some products, i.e., helmet, rackets, etc., are made using textile reinforced composite materials. The particular objectives of such products are strength, protection, and light weight structure. The other products (swimwear, sleeping bags, track suits, ropes, etc.) are made purely from textile materials. The sportech products are made of synthetic fibers due to their superior properties (wicking, strength, etc.) than the natural fibers [15].

3.2.10 Geotech

Geotech stands for geotextile products. According to ASTM "A permeable geosynthetic comprised solely of textiles is called a geotextile product" [16]. These products are made to be used in geotextile applications. The examples of some geotech product are:

- Geo-grids.
- Geo-nets.
- Geo-composites.

The major functions that Geotech products perform are reinforcement, stabilization, separation, drainage, and filtration. The application areas could be civil engineering (roads, tunnels, bridges, dams, and buildings), irrigation (canals and rivers), and environmental engineering (landfills and waste management). These products should have good strength, durability, and low moisture absorption. Therefore, synthetic fibers are used to manufacture these products most of the times. Majority of the products are nonwoven however; woven products are also used in some applications [17].

3.2.11 Protech

Protech is one of the largest groups of technical textile products. The products used for personal or property protection are considered under the umbrella of Protech. Some of the relevant products include:

- Cut/stab resistance clothing.
- Firefighter clothing.
- Antimicrobial clothing.
- Waterproof clothing.
- High-visibility clothing.
- NBC (nuclear, biological and chemical) protective clothing.
- High altitude clothing.
- Bulletproof vest.
- UV protective clothing.
- Clean room clothing.

As all of these products have to provide protection, therefore most of the times synthetic or high-performance fibers are used in these products. Aramids are used for protection against fire (firefighter clothing), impact (bullet proof vest), cut (butcher's gloves), and abrasion (biker's clothing). Other fibers may include carbon, glass, stainless steel (clean room clothing), etc.

3.2.12 Oekotech

Oekotech contains the technical textile products related to the protection of environment and ecology. The most common application areas are filtration, recycling, erosion control, and water efficiency. This is not a well-defined segment yet rather it overlaps with many other segments, i.e., Indutech, Geotech, and Agrotech. Most of the times it is focused on environment protection, waste management, and recycling [4, 18]. Filtration is the most important function dealt by oekotech.

It is evident from the discussion earlier in this chapter that the current classification of the technical textiles is based on the application areas. It has basically two problems. First of all, several segments of the technical textile do not have clear boundaries and overlap with the other segments. For example; Oekotech overlaps with Indutech (filtration), Geotech (erosion protection), and Agrotech (water efficiency) [18]. Another example is that Protech overlaps with almost all other segments (hometech, clothtech, sportech, etc.). For example, helmets are a part of Protech as well as Sportech at the same time.

Secondly, this classification does not help much to an entry level manufacturer. It is almost impossible to figure out a certain type of manufacturing facility to fulfil the needs of one segment. The reason is that each segment has a large variety of products made of diversified fibers/raw materials using divergent manufacturing techniques and equipment. In addition to that, the products have to fulfil varied testing requirements as well. Keeping in view the facts explained, there is a need to classify the technical textile products in a different way.

3.3 Components of a Technical Textile Product

Any of the technical textile products has three components, i.e., material(s), structure, and design. For example; if someone wants to develop a suit for firefighters, the first step will be the selection of the raw materials. For that, the developer must understand the requirements of the product. The most important and premier requirement will be the protection from fire (high temperature) for a certain time period. Further, requirements comprise of cut resistance (protection from sharp edges and glass etc.), impact resistance (the firefighter may have to break a glass window), and moisture management (the firefighter will sweat heavily due to the high temperature which needs to be sent out of clothing to achieve thermal comfort). So the developer will have to choose the right materials for the exact level of protection.

Secondly, the developer will have to finalize the structure of the product. Normally, such products have to fulfill complex and multifunctional requirements to meet the goal of their existence. Therefore, complex and multilayer structure are commonly used. For example a common firefighter suit will consist of a three layer structure, i.e., outer shell, moisture barrier, and thermal barrier. Thermal barrier layer is the most important part as the firefighters are exposed to extremely high thermal energy in case of a fire incident. Moisture barrier has to protect the firefighter from hot water, chemicals, and other liquids. The outer layer's function is to protect the other layers of the suit [19].

Thirdly, the design of the garment must be finalized. For example, the developer must understand the requirements of the firefighter during a fire incident. The firefighter needs some tools (to facilitate his work) and a radio (to stay connected outside). These things must be present at a place where they are easily and quickly reachable by the firefighter. Further, his dress must have reflective tape (front and back side) so that he could stay visible to others in smoke. Therefore, the design of such products is equally important as the material and structure of the product. The product will only be useful if all the three components are equally efficient.

3.4 Classification of Technical Textiles Based on Technology

It will be more logical to classify the technical textile products based on the manufacturing technology. This kind of classification will be useful for the small scale/new manufacturers. Following are the technologies that could be used to make different types of technical textile products. Most of the products need multiple technologies to develop a complete product.

3.4.1 MM Fiber/Filament Development Technology

The major raw material for the technical textile products is the manmade fibers. The manmade fibers can be made by using melt spinning or wet spinning. Different types of monomers can be used to make manmade fibers. The required monomer(s) are converted into a long chain polymer with the help of polymerization process. The polymer is collected in the form of chips/granules. Then these polymer chips are passed through the process of melt spinning. In melt spinning process, the polymer chips are melt keeping in view the glass transition temperature of the polymer. Then the molten polymer is passed through a spinneret. The spinneret is usually a machine part which contains several small wholes through which polymer is extruded. After the polymer strands leave the spinneret, they are drawn to align the polymer chains. Then the polymer is cooled down and collected.

Wet spinning process is almost similar to the melt spinning process to accept two things. Firstly, the input of wet spinning is polymer solution while in melt spinning polymer chips are used. Secondly, the fibers are collected in a solution (wet environment) while in melt spinning the fibers are collected in a dry environment. After that the fibers are drawn, washed, dried, and collected.

With the help of manmade fiber manufacturing techniques, it is possible to make fine, continuous, and uniform fibrous strands with large surface areas compared to the natural fibers. The large surface area can be beneficial in several applications, e.g., wicking, moisture transport, etc. Further, it is also possible to mix several materials/polymers and convert them into filaments (e.g., bicomponent, tricomponent, etc.). This way multifunctional filament can be created which can then be used in different technical applications. E.g., metallic particles can be mixed with a polymer to make it antibacterial.

3.4.2 Yarn Manufacturing Technology

Unlike conventional yarns, technical yarns can be developed using the similar manufacturing setup using small attachments. Technical yarns have several applications in technical textiles. E.g. technical sewing threads, conductive yarns, etc. Corespun yarn is one of such examples. A core spun yarn has comparatively better strength than a similar staple spun yarn. In addition to that, two different materials can be used in core and sheath. This way, an advantage of both the materials can be taken at the same time. Further, sewing threads, which need more strength, elongation and twist balance to run smoothly during stitching process, are made by using the processing doubling and twisting. Normally, more than one yarns are taken and twisted together. It is made sure that the twist is given in the opposite direction, i.e., if we have Z twisted yarns then we will twist then in S direction during the process of doubling to balance the twist and avoid snarling.

3.4.3 Fabric Manufacturing Technology

The most commonly used fabric manufacturing techniques in conventional textiles are weaving and weft knitting. Other techniques like nonwoven, braiding, 3D weaving, and warp knitting have a large number of technical applications.

There are two major steps in the manufacturing of nonwoven fabrics, i.e., web formation and web consolidation. The web for nonwoven fabrics can be made by using dry laid or wet laid techniques. Dry laid and wet laid have several manufacturing techniques but those are not in the scope of this chapter. Once the web is formed, it can be bonded using mechanical, thermal, or chemical bonding techniques. The advantages of using nonwoven fabrics are high production speed, low cost, versatility, etc. Synthetic fibers are mostly used to make nonwoven products. These products may be used for absorbency, filtration, insulation, and packing. Some of the nonwoven products are as follows:

- Bags/sacks.
- Face mask.
- Diapers.
- Protective suits.
- Wipes.

Braiding is a technique in which multiple strands of yarn are interlaced with each other to make a cord. The cord may either be flat or circular. Braids are made of using almost all types of fibers (cotton, polyester, jute, Kevlar, etc.). Some of the braided products are as follows:

- Jumping rope.
- Climbing rope.
- Parachute links.
- Draw cords.
- Shoelaces.
- Cable covering.
- Hoses.
- Bracelet and accessories.

Three-dimensional weaving (3D weaving) is a type of weaving in which fabrics reasonable thickness are developed. In this type of weaving, there are yarns which pass through thickness of the yarn sheet and interlace them to make a 3D structure. The biggest application of these structures is in composite materials. Three-dimensional woven structures are used as a reinforcement in the composite materials. All types of fibers can be converted into 3D woven structures. The selection of the fiber is dependent on the end use of the product.

Warp knitting is a technique in which a warp sheet is prepared (similar to weaving process) and then this sheet is placed on a warp knitting machine which converts it into knitted fabric. Warp knitted fabrics have better dimensional stability as compared the weft knitted fabrics. Weft knitted fabrics are mostly used in conventional textile products. On the other hand, warp knitted fabrics are used in technical textile products. These fabrics are used in following applications.

- Lingerie.
- Sportswear lining.
- Mosquito nets.
- Bags lining.
- Shoes lining.
- Blankets.

3.4.4 Nanotechnology

Nanotechnology is a new emerging domain. This technology deals with the development and usage of nano materials (nano particles and nano fibers). Nano fibers are developed by using electrospinning. In this technique two metallic plates are electrically charged with opposite charges using a high voltage source. Then solution of a polymer is injected from an electrically charged plate. At the same time the oppositely charged plate collects the fibers due to attraction among opposite charges. As the potential difference between two plates is very high, the developed fibers are of nano size.

The advantage of using electrospinning is that the developed nanofibers have a very high surface area. Therefore, they can be used for absorption, separation, filtration, and drug delivery in the form of a nano web/sheet. Further, multiple polymers can also be mixed together to make multifunctional nano fibers. The disadvantages of this technique are that the fibers developed with this method have poor mechanical properties and the production speed is very slow. Due to slow production speed, it is difficult to make nano fibers in bulk quantities. The scientists are working on different possibilities to increase the production speed of this process. The web/membrane made from electrospinning is used by sandwiching between multilayer structures due to its mechanical properties.

Nanoparticles of several materials are being used by the researchers. The nanoparticles are usually applied on a textile substrate with the help of a binder. These particles may perform several functions, e.g., antimicrobial, self-cleaning, anti-wetting, etc. The advantage of using the nanoparticles is that the surface properties of the substrate are not affected much.

3.4.5 Coating

Coating is a technique in which coating material is applied on a textile substrate to achieve a certain characteristic. The most commonly used coating method is knife coating. In this method, a substrate passes beneath a tilted knife. The coating material is placed on the fabric. When the fabric passes under the knife, it applies pressure on the substrate and the coating material is penetrated in the substrate. Both single sided and double sided coating machines are used in the industry. Some of the applications of coated fabrics are as follows:

- Shower curtains.
- Car seat covers.
- Airbags.
- Canopies.
- Umbrella.

Almost all types of fibers (cotton, polyester, polyamide, etc.) can be used as substrate for coating. Coated material may also contain certain types of finishes which are applied at the same time. These fabrics are usually used for protection.

3.4.6 Smart Textiles

Smart textile is a newly emerging domain of technical textiles. These are the textile products which can interact with the environment and can respond to the environmental changes. Smart textile products can sense a stimulus, transmit a signal, process the received information about a stimulus and respond according to the situation. Electrical conductivity is the basic function required for such products. Textile materials are usually insulators but flexible. On the other hand, the conductive materials (wires) are conductive but too stiff to be used in textile products. Keeping in view this requirement, scientists have been working to develop flexible conductive materials. The applications of smart textiles can be found in sports, leisure, healthcare, military, and fashion [20]. Some of the example of smart textile products are as follows:

- Smart bed sheet.
- Smart shoe.
- Smart socks.
- Monitoring vest.
- Heating vest.
- Smart football.

All these products have some additional functions which normal products do not have. For example, smart bedsheet can make it up automatically in the morning. Monitoring vest can monitor your body vital signs and send this information to your smart phone/cloud.

3.4.7 Composite Technology

The products made with this technology have two structural parts, i.e., reinforcement and resin. The function of reinforcement is to provide the strength to the structure while the resin, after hardening, provides a certain shape to the product. A number of materials can be used as reinforcement (glass, carbon, etc.) and resin (epoxy, saturated polyester). The choice of material depends on the requirement of the end product. Stronger and light weight products can be made by using high-performance fibers (carbon) but the cost of the product also depends upon the choice of the material. Composites are famous for their strength, durability, and weight. Some of the examples are as follows:

- Shades.
- Automobile bumpers.
- Aeroplan parts.
- Sports goods (hockey, rackets, etc.).
- Safety helmets.
- Luggage bags.

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Chapter 4
Fibers for Protective Textiles

Khubab Shaker and Yasir Nawab

Abstract "Protective Textiles" is collectively used for the textiles and clothing employed necessarily in a specific work environment, either in labs, hospital, battlefield, rescue, or industrial applications. These textiles and clothing normally focus on the functional aspects rather than the aesthetics. The recent trends in these protective clothing include strong, lightweight and safer product for a particular end use. This chapter is focussed on the fibers used for protection against certain hazards/phenomenon like impact, chemicals, fire, heat, ballistics, etc. The majority of these application areas use high-performance fibers, to meet the challenges. But, the textiles for protection are highly specific, depending on the application area. The product for a particular end application needs to exhibit properties that may not be required for other applications. The products based on these fibers are also discussed briefly in this chapter.

4.1 Introduction

The term "Protective Textiles" is collectively used for the textiles and clothing employed necessarily in a specific work environment, either in labs, hospital, battlefield, rescue, or industrial applications. These textiles and clothing normally focus on the functional aspects rather than the aesthetics. The recent trends in these protective clothing include strong, light weight, and safer product for a particular end use. Therefore, the manufacturers are constantly improving the existing products and introducing new materials to meet the constantly increasing/ever changing demands. This chapter is focussed on the fibers used for protection against certain hazards/phenomenon like impact, chemicals, fire, heat, ballistics, etc. The majority

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of these applications areas use high-performance fibers, to meet the challenges. The products based on these fibers are also discussed briefly in this chapter.

The textiles for protection are highly specific, depending on the application area. The product for a particular end application needs to exhibit properties that may not be required for other applications. For example, in case of ballistic protection, the chemical resistance is a very less concerned phenomenon., the mechanical behavior of fiber is more concerned in ballistics, but it is of little use in heat resistant applications. Some of the main properties concerned for protection include tensile properties, temperature resistance, flammability, chemical resistance, impact behavior, and limiting oxygen index (LOI). These properties largely determine the behavior of a fiber in a particular application.

4.2 Material Selection Criteria

Therefore, it is necessary to define a basic criterion for the selection of material for textile product design. It is required to define a material selection process based on the properties of materials available. A problem statement is established first, keeping in mind the performance criteria. The material is then selected by careful consideration of its performance, specific design and cost parameters. Some of these parameters are discussed below in detail.

4.2.1 Mechanical Performance

The mechanical performance of the material is the most critical parameter while selecting the fibers. The mechanical performance is necessary for the durability and structural integrity of the structure. Therefore, it is necessary to identify the stresses that will be acting on the product. Stresses maybe either tensile, tearing, compression, bending, shear, etc. Hence the mechanical properties that need to be considered include breaking strength, yield strength, elongation, toughness, and stiffness. Based on these parameters, the materials may be termed as brittle, strong, ductile, or plastic material (Fig. 4.1).

Therefore, a sound knowledge of the mechanical properties of the material is necessary for a particular application. These properties have been defined and discussed below:

Breaking strength

Breaking strength is generally the most important parameter considered before the selection of material for a particular application. The high strength fibers (e.g., para-aramid) offers up to 8 times high breaking strength as compared to the steel. These fibers also have a high strength-to-weight ratio making an ideal choice for lightweight and enhanced strength applications. In case of applications where strength is not of

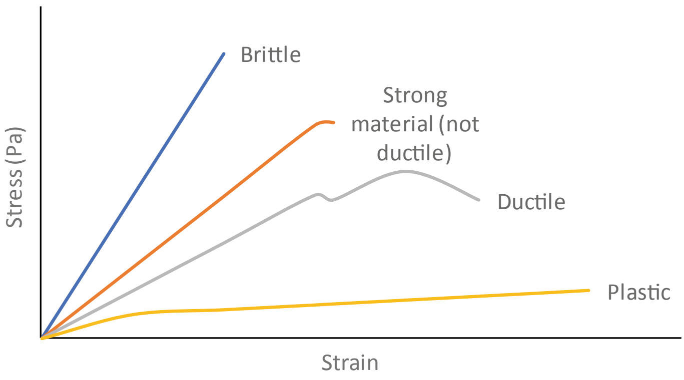


Fig. 4.1 Stress strain curves of differnet materials

principal importance, other mechanical properties are considered before material selection.

Yield strength

The yield strength explains the material strength at the end of elastic region. It approximates the elastic limit of the fiber, i.e., the upper limit of load that can be applied to the fiber. It is defined as the maximum amount of stress that a fiber can bear before it undergoes permanent deformation. Therefore, it is an important parameter in the product design.

Elongation

The ductility or brittleness of the material is best explained in terms of its elongation (strain). It is the % change in the material length from original length, either at yield point or failure. Ductility is the ability of a material to be stretched without becoming weaker/brittle in the process. The more ductile it is, the more formable the product is.

Toughness

The resistance offered by a material to fracture when it is stressed is termed as material toughness. It is also expressed as the ability of a material to absorb energy and deform plastically without fracture and is calculated as the amount of energy or energy per unit volume of the material. The toughness is a time/temperature dependent phenomenon sensitive parameter, particularly at elevated temperatures. The toughness of the material must be considered in impact and shock absorption applications. The parameter is highly application oriented and requires extensive testing to realize the effectiveness of a material for particular application.

Stiffness

Stiffness is the ease of deformation produced in the material under an applied load. The elastic modulus, defined as the ratio of stress over strain in the elastic range is a measure of material stiffness. As it is a material property, therefore it remains constant for a particular fiber. The modulus is measured under tensile, flexural, compression or torsion load.

4.2.2 Chemical Resistance

The shape/properties of a material are largely affected by certain chemicals/solvents. The ability of a fiber to maintain its properties and shape in a certain chemical environment for a specific time is termed as its chemical resistance [1]. The chemical resistance offered by a fiber depends on its molecular structure, concentration of chemical reagent, exposure time, temperature, and applied stresses. A mixture of chemicals may also affect the material in a more detrimental way as compared to a single chemical, e.g., one chemical may swell the material while the other may saturate the material and react with it. The additives present in the material (colorants, fillers, contaminants, etc.) also affect the chemical resistance of material. Hence, it is important to know how a material will behave in a chemical environment.

There materials are affected by chemical reagents in two possible ways:

1. Chemical reagent dissolves the polymeric material by acting as a solvent.
2. Chemical reagent act as a stress cracking agent.

The first technique results in dissolution of material, leading to the loss of properties (physical, mechanical, thermal, electrical, etc.), dimensional change (swelling, mass loss, etc.), degradation, etc. This approach helps to determine the solvent resistance of a fiber, and the solvent may also initiate cracks in the fiber. But the test conditions and procedures for chemical resistance are not standardized in terms of reagent concentration, time, and temperature. Also reporting the effect of chemical reagent on the material varies, e.g., volumetric swelling, dimensional change, weight pickup, mechanical performance, etc.

The chemical resistance of a material is determined by its chemical structure including type of bonds, bond length, branching, crystallinity, and energy required to break the bond. For example, polytetra-fluorethylene (PTFE) is resistant to majority of chemicals due to its crystalline structure, strong C–F covalent bonds, and lack of branching. In case of nylon fiber, the regular symmetrical structure produces a highly crystalline fiber, while the strong intermolecular attractions give a strong, rigid, and chemical resistant. The amorphous materials are more susceptible to chemical attacks, while semi-crystalline materials perform better than the amorphous materials.

4.2.3 Thermal Resistance

Thermal resistance defines the ability of a textile fiber to serve as a heat insulator. Higher the value of thermal resistance, lower is the loss of heat across its surfaces.

$$R = \frac{\Delta T \cdot A}{\dot{q}},$$

where ΔT is the temperature difference between material surfaces, q is the heat flow, and A is surface area [2]. It is the most critical parameter for the applications where change in temperature is unavoidable. The temperature deteriorates the mechanical/chemical performance of material, also the phenomenon of oxidation and corrosion is expected to increase with rise in temperature. The thermal resistance is a function of fabric thickness and structure. It also depends on the thermal conductivity of the material. The higher value of thickness results in an increase in thermal insulation provided by the fabric.

Different approaches/devices are being used to determine the thermal resistance of textile fabrics. Some of these include Permetest, Skin model, Thermo Labo, Guarded hot plate, and Thermal Manikin system [3]. In case of guarded hot plate, the sample is placed over a hot metal plate, and change in temperature on both sides of sample is recorded. Thermal resistance is then calculated using plate surface area and temperature difference between the fabric surfaces. The resultant value of thermal resistance includes intrinsic resistance of the specimen and some transition resistance from fabric to air (corresponding to the heat loss from fabric surface to the environment).

4.2.4 Flammability

The ability of a material to burn/ignite, causing its combustion. It is generally determined by fire testing, as the degree of difficulty to cause combustion of material and classified into highly flammable, flammable and non-flammable materials. Owing to the flammable nature of the material, its use may be limited for a certain application [4]. The flammability is improved by the addition of flame retardants that work by delaying the ignition or retarding the burning process once it starts, and/or suppressing the formation of smoke [5]. The flammability of a material is expressed in terms of its ignitability, burning/heat release rate, flame spread, smoke generation, and toxicity [6]. These terms have been discussed briefly.

Ignitability

It is the resistance offered by the material to ignition and is the most serious parameter of flammability because in the absence of ignition, there will be no fire.

Burning/heat release rate

The solid fuel pyrolyzed per unit area in a unit time explains the burning rate of the material. the burning rate determines the heat release rate and the combustion products generated due to burning.

Flame spread

Another important measure of flammability is the flame spread. It is an indicator of fire hazard because burning area is increased due to flame spread resulting in a higher heat release rate. The flame spread may be considered as a series of piloted ignitions giving rise to increased burning area. The ratio of a heating length ahead of pyrolysis front to the ignition time s termed as the flame spread rate.

Smoke generation and toxicity
In addition to the fire itself, there are some other causes of death due to fire. The two major factors include the reduced visibility due to smoke generation (reduced wayfinding ability), and suffocation, unconsciousness or incapacitation (by inhaling toxic gases) may lead to death. The reduced visibility during a fire is caused by smoke opacity and its irritant nature. The presence of soot particles makes the smoke opaque while irritation is caused by irritants like hydrogen halides (HCl, HBr, and HF), formaldehyde, nitrogen oxides, sulfur dioxide, phosphoric acid, etc. The overall toxicity is dominated by the presence of carbon monoxide and then HCN. The intoxication by CO is quite slow while that of HCN is rather sudden.

Flammability tests
The common flammability tests to identify the material properties are performed as follows.

Ignition
The ignition test is generally conducted at a small-scale using Cone Calorimeter, Fire Propagation Apparatus (FPA), or LIFT apparatus. These tests involve the irradiation of a small sample at a prescribed radiant flux. The time for piloted ignition in the presence of a small pilot is recorded. The sample size is 100 × 100 mm in Cone Calorimeter and 155 × 155 mm in the LIFT. Both LIFT and Cone Calorimeter are performed in the normal air, while FPA is performed in 40% oxygen concentration. The resulting parameters include critical heat flux for ignition and ignition time as a function of applied heat flux. Another measure of ignition/flame spread in a polymer is the Limiting Oxygen Index (LOI). It is the lowest fraction of oxygen that will support burning on a small sample. This test is frequently applied to polymers according to the ASTM D 2863.

Heat release rate
The heat release rate (HRR) measurement is generally performed using Cone Calorimeter or Fire Propagation Apparatus. HRR is calculated on the basis of oxygen consumption during a calorimetric measurement, as the amount of heat released per unit mass of oxygen consumed remains approximately constant. These tests also provide transient measurements of mass loss rate and specimen generation (yield) rate in addition to HRR.

Flame spread
The flame spread is tested for lateral and upward direction separately. The lateral flame spread is evaluated using LIFT apparatus. Initially a sample having dimensions 155 × 800 mm is exposed to a decaying heat flux from methane fired radiant panel. After reaching the thermal equilibrium, sample is ignited in the high heat flux region.

The flame spread in lateral direction is measured as a function of radiant heat flux (incident).

The upward fire propagation test is performed according to the ASTM E2058 using FPA. The sample used for testing has a width and height of 100 mm and 600 mm, respectively. The pilot flame is used to ignite bottom 120–200 mm of sample at a heat flux of 50 kW/m^2. The pyrolysis front is tracked during the test as a function of time. The spread is then recorded in terms of fire propagation index (FPI) using thermal inertia, heat release rate and effective ignition temperature.

Smoke production and toxicity

The toxicity of a flame is usually expressed in terms of LC50 concentration. It is defined as the mass of material per unit volume that results in death of 50% of the exposed animals. It is performed by gasifying the material under non-flaming conditions at 25 °C less than its ignition temperature and measuring the chemical composition of the atmosphere.

4.3 Fibers for Impact/Crash Applications

The terms impact or crash are associated with the sudden and abrupt change in velocity imposed to the human body. The abrupt acceleration imposed on the human body may cause injuries, damage to property, or may be fatal. The level of injury is defined by the magnitude, duration, and direction of application of accelerating forces. The inertial forces resulting from the application of acceleration cause displacement of organs within the body with equal and opposite acceleration and may cause damage to the vitals [7]. Few examples of crash impact from daily life include:

- Collision of a vehicle with another vehicle, obstruction, or pedestrian.
- Falling from height on the ground.
- Thrust on the crew in military jet aircraft during crash.
- Physical assaults with unconventional weapons e.g., bottles, bats, metal bars.

Keeping in view the above discussion, it is important to introduce/implement the restraint systems to limit the human body damage during a crash event. For example, the use of seat belts while driving and the use of helmets while driving a motorcycle has been enforced by law in many countries. These measures, enforced by law or adopted by choice, help to reduce the risk of serious injury from crash impact. Some of the restraint systems and fibers used for these systems are discussed in detail.

4.3.1 Seat Belt

In a vehicular collision, seatbelt is a vital product for energy ingesting, keeping the passengers safe from injuries and casualties. It keeps the passengers being ejected from the vehicle and reduces the actual force of impact. Seatbelts comprise of one or more straps, secured across the trunk of seated individual by means of a quick-release buckle. The conventional type is the lap strap, which is easy to use but does not restrains the upper trunk and may result in serious injury. The three-point seatbelt was developed by the addition of a diagonal strap that runs from one of the lap straps, passes over the front of trunk and then over the top of opposite shoulder, and finally secured to the vehicle/seat.

The five-point harness is introduced for use in modern fighter aircrafts it comprises of two lap straps, two shoulder straps and a strap between legs from seat structure to the quick-release box. This harness provides excellent restraint properties for maneuvering, crash impact, or ejection. The seat belt has to resist a load of approximately 14KN during a crash event and performance of the complete seat belt system is measured. Seat belts are equipped with a load limiting retractor, a pre tensioner and a D-ring which helps in reeling out of the belt from the retractor [8, 9].

The mechanical performance of webbing (seat belt structure) is established in terms of different properties like breaking strength, elongation at break, width and thickness of webbing and abrasion resistance. These properties are determined at conditions that resemble the real-life scenario. For example, the strength of seatbelt structure is usually determined by means of conventional slow strain rate (so-called static tension testing). The test method AS 1753–1990 [10] is implemented to test the tensile strength of structure.

The initial seatbelts were produced from natural fibers like cotton, flax, and wool but filament yarns are preferred these days due to their enhanced strength. The filament yarns used include synthetic fibers like Nylon, Polyester, Polypropylene, p-aramid, UHMWPE, etc. The synthetic materials mostly preferred are the polyamide (Nylon 6.6) and polyester. Polyamide is used to produce Lap belts, while polyester is preferred for the diagonal range of seatbelts. The properties of both these fibers have been compared in Table 4.1. The polyester is considered superior due to high stiffness and low extensibility and better UV degradation resistance [11].

Table 4.1 Comparison of polyester and nylon 6.6 basic properties [12]

	Polyamide (Nylon 6.6)	Polyester
Specific gravity (g/cm^3)	1.12	1.39
Specific heat capacity, Cp (J/kg.K)	1670	1300
Melting point (°C)	265	255
Glass transition temperature (°C)	50	75
Energy to melt (kJ/kg)	589	427

The seatbelts are usually woven structures that are 48 mm wide [13]. These structures are woven using coarser yarns, for better abrasion resistance. Another objective of using coarser yarn is to achieve maximum yarn packing factor and strength. The polyester seatbelts are woven with a warp and weft yarn linear density of 110 tex and 55 tex, respectively, are used, with 320 warp yarns giving 46 mm wide belt. The polyamide seatbelts have warp and weft yarn linear density of 18 tex and 47 or 94 tex, respectively [12]. Generally, 110–167 tex is the most optimum choice for body warp yarns and 27–55 tex is used for selvedge yarns. The weft yarns are either of the same linear density as selvedge yarns or slightly coarser. For warp yarn having linear density of 110 tex, 320 threads are used, while 260 yarns are used for linear density of 167 tex.

In addition to the material, the interlacing pattern of warp and weft also decides the wearer protection during an impact. The seatbelts are either single layer or double-layered structures, with plain, twill, and satin weave designs [14]. The initial webbings were produced in plain weave using either wool, cotton or flax yarn. Currently, the 2/2 herringbone twill is widely used because it gives a compact structure with maximum threads density [15].

4.3.2 Airbag

Another restraint system in automobiles is the airbag system that enhances the human tolerance during impact acceleration. The air bag is located at the front of seat occupant and inflates automatically (inflation time < 0.1 s) in response to deceleration and prevents the occupant from moving forward and striking the vehicle structure. The airbag, jointly with seat belts assures passengers safety in the case of a car accident and reduces front-seat occupants' fatality risk by 61% [17]. The four common types of airbags are: side airbags, front airbags, knee airbags, and inflatable seat belts. Airbag system uses a textile cushion, folded and tucked in the steering wheel along with propellent and inflator assembly and crash sensor. The crash sensor detects the collision and triggers the gas generator to inflate the textile cushion. The airbags are prepared traditionally by cutting the fabric in proper shapes and sewing, internally and externally, to join the two sides properly. However, the one-piece-weaving (OPW) technology is also being used to eliminate the need for cutting and sewing.

The airbags were also used in Mars missions to cushion the spacecraft while landing on the rocks or rough terrain and allow it to bounce across the surface of Mars. These airbags were produced with high strength Vectran fiber [16]. The linear density of HS Vectran used was 200 den and woven in plain weave. The fabric areal density was 92 grams/m^2, while its tensile and tear strength was 85 N/mm and 665 lbs, respectively. It was then coated with low-temperature silicone to minimize the air permeability. The adhesion strength of this coating was 31.2 N, the coating weight was 54.25 grams/m^2 and coated fabric weight was 146 grams/m^2. To protect this airbag from sharp edges of rocks during impact landing, an outer abrasion layer was used. This multi-layer approach allowed the movement of inner airbag in the event of rock impingement, and damage was limited to the outer layers only. It was also woven using 200 denier Vectran in a ripstop weave with an areal density of 82 grams/m^2, and 4 plies were used as outer layer [17]. Vectran is spun from liquid crystal polymer (LCP) and exhibits exceptional strength and rigidity. The unique properties of Vectran include [18]:

- High modulus and strength.
- Excellent creep and flex properties.
- High abrasion and chemical resistance.
- Minimal moisture absorption.
- Low thermal expansion coefficient (CTE).
- Excellent property retention at high/low temperatures.
- Outstanding cut resistance and vibration damping.
- High impact resistance.

The fibers used for weaving airbag fabrics for automobiles are required to possess high strength, energy absorption capacity, thermal stability, better coating adhesion, and functionality in extreme environmental conditions (cold and hot). The fabric may be coated or uncoated but the it must be impermeable to air. In majority cases, the fabric for airbags is woven using Nylon 6.6 multifilament yarn (linear density 420 to 840 den), but other materials like polyester, nylon 4.6, nylon 5.6, and nylon 6 are also used [19]. The uncoated fabric weighs about 170 and 220 grams/m^2. The polyamides are usually preferred due to:

- High-strength-to-weight ratio, resulting in strong woven fabrics.
- High elongation, helping in circumferential stress distribution uniformly.
- Material toughness, enables to withstand stresses during airbag deployment.
- High specific heat capacity, heat of fusion and melting point.

A comparative analysis of the fibers used for the seatbelts and airbags is given in Table 4.2. The polyester is not preferred development of airbags due to its lower thermal properties. Contrary to the nylon 6.6, polyester needs about 40% less amount of heat to melt and the fabric has high permeability allowing the diffusion of hot gases [14].

4.3.3 Safety Helmets

The protection of head is most important as one third to half of car crash fatalities are due to the head injuries. The head injuries may include fracture of skull bone, tearing of membrane lining inside skull or localized damage to the brain. The brain may be damaged either by physical damage to the skull or by the blow (acceleration of the head) in the intact skull, where brain moves within the skull. The blow head blow may result in concussion (transient paralysis of cerebral function), leading to unconsciousness. These conditions are followed by complete recovery.

Table 4.2 Yarns used for seatbelts and airbags

Application	Fiber	Fineness	Strength	Modulus	Elongation (%)	References
Seatbelts	Nylon 6.6	18 tex, 47/94 tex	40–60 cN/tex	20–35 cN/tex	20–30	[12, 15, 20]
	Nylon 6.6	130 tex, 65 tex				
	Polyester	110 tex, 55 tex	25–85 cN/tex	800–1000 cN/tex	10–20	[12, 15, 20]
	Polyester	130 tex, 65 tex				
Airbags	Polyester	330–470 dtex	60–75 cN/tex	–	15–30	119–120
	Nylon 6.6	630 denier	9.3 g/den	–	15–30	122
	Nylon 6.6	350 dtex	60 cN/tex	–	15–30	118
	Nylon 6.6	100–800 dtex	5–11 cN/tex	–	15–35	124
	Polyester	540–650 denier	5.1–8.5 g/denier	–	15–20	
	Vectran	200 denier	24.4 g/denier	838 g/den	2.8	[18]

The head injury is not only limited to the head protection but also includes other factors like trunk restraint and space free of rigid structures around head. Another aspect is the use of a surface that deforms when head may come in contact, allowing maximum energy absorption without damage. However, the most satisfactory solution is the provision of personal head protection.

A protective helmet usually comprises of an outer shell, with a layer of crushable foam inside and a strap harness. The shell helps to distribute the impact energy, while gap between shell, and head (18–25 mm) reduces the acceleration applied to the head during impact. The strap harness helps to fasten the helmet on head and avoids taking off. Thus the protective helmets help to reduce the fatalities and head injuries in car/motor cycle crash [7].

Two major components distinguished in the helmets are the outer shell and the inner layer for shock absorption. The materials that are commonly used in the motorcyclist helmets shell are carbon fiber, polycarbonate, and fiberglass. Thermoplastics as well as composite materials are in practice to apply for helmets. Standard helmets shell is usually made of polycarbonate and inside this a layer of expanded polystyrene foam (EPS) is inserted [1]. This combination will provide a stiff material but also perfectly crushable during impact. In advanced helmets multiple densities of EPS in various layers and locations are used. This creates a smarter helmet, which have ability to absorb the crash depending on the severity and location of impact. The drawback of using EPS is that denser foam will bear high impact energy, but it eventually increases the weight of product and make it uncomfortable for users as a thick, heavy foam helmet is simply not comfortable to wear on the other hand soft foams will crash easily. Expanded polyurethanes foam is also in practice to apply as inner layer but it is heavier than EPS.

Other high-performance materials used in advance helmets are, Zorbium, SALi (Shock Absorbing Liquid), ABS plastic and Nylon [21]. The manufacturing process for shell used for helmets from thermoplastics materials (PC, ABS) is injection molding in which molten material is injected into die having core and cavity at specific temperature and pressure.

4.3.4 Shock Absorption

The term shock describes a sudden acceleration or deceleration, due to a strike, drop or other external factors. While the impact is an extreme shock applied over a short time period, e.g., due to collision of two or more objects. Some other examples include vehicular accidents, physical assaults with bats, metal bars, bottles, or falls from height. Shock-absorbing cushions are used specifically for these situations. It is recommended to use viscoelastic materials, that absorb the impact effectively. Dupont has introduced a multi-threat-protection (MTP) armor for chock protection, in addition to other threats.

4.3.5 Parachutes

Parachutes are the devices that help to slow down the descent of the body falling from the atmosphere or the velocity of the body traveling horizontally. It is a combination of two French words para (means protect) and chute (means the fall), giving it the literal meaning of fall protection. Hence it can be defined as a protection device when one falls from height under the action of gravity [1]. The parachutes are being routinely used for sky jumping activities both in the military and sports area, decelerating race cars, boats, aircraft seat ejection system, and bombs stabilization.

The main parts of a parachute are the canopy, suspension line, slider, and brake loop. Canopy is a structure made of fabric cells that forms a rectangular surface when filled with air, with the aerodynamic properties of an airplane wing. Suspension line is the set of cables that connect canopy to harness (straps) connected to the sky diver. Slider slows down the deployment of canopy to absorb the impact of deceleration as it opens up, while brake loop is the cable that helps to control the direction of parachute [22].

The parachute canopy was initially made of canvas (plain-woven fabric from cotton or linen) but was replaced by silk in due course of time. The silk fabric was selected due to its lightweight, strength, fineness (thin), fire resistance, and easy of

Table 4.3 Properties of fibers used for parachute canopy

Parameter	Cotton	Linen	Silk	Nylon
Fineness (dtex)	1–4	10–40	1–3.5	14–330
Fiber length (mm)	10–60	200–800	700–1500	Continuous
Density (g/cm^3)	1.5–1.54	1.43–1.52	1.37	1.15
Moisture regain (%)	8.5	12	9–11	4
Breaking strength (cN/tex)	25–50	30–55	25–50	40–60
Elongation (%)	5–10	2–3	10–25	20–40

folding. The shortage of silk was observed during World War I and II, leading to the idea of replacing the silk with some synthetic fiber like nylon. It was selected due to its good elasticity, mildew resistance, better strength, and relatively low cost. Recently, other fabrics like p-aramid and Dacron polyester are also used for canopies, but nylon is still the most popular material (Table 4.3).

The nylon fabric for parachute canopy is woven in plain weave to give a pattern of small squares. These squares are created by using an extra-thick thread, that helps to avoid tearing of the fabric. Such type of weave design is also referred to as ripstop and is produced using either a double or extra-thick thread at regular intervals. The ripstop structure enhances tear resistance and keeps small tears from spreading [22]. Being lightweight, strong, and flexible, the nylon is also used to make harness straps and suspension lines of the parachute.

The overall comparison of the fibers used in impact/crash applications is given in Table 4.4, w.r.t the strengths, weakness, and uniqueness of each fiber.

4.4 Chemical Resistant Fiber

The chemically resistant fibers are designed to offer resistance in chemical environments for a certain period during their service life at ambient and elevated temperatures. Some of the common areas of application include gas and liquid filtration fabrics, braiding materials in chemical plants, protective textiles, high-performance sewing threads, and conveyer belts. The chemical protective clothing requires specific chemical resistance for a relatively small period of time intermittently at elevated temperatures, while a long-term durability to less corrosive environments is demanded in geotextiles, where ambient conditions prevail. The chemical inertness in these fibers is obtained either by strong chemical bonds in the polymer backbone, absence of reactive side groups, or backbone free of hydrolysable groups (e.g., ester, amide) [23]. Owing to the chemical inertness of these fibers, they may also overlap with other fibers more often considered to be heat resistant or flame-resistant fibers.

Hence the polyethylene and polypropylene fibers offer acceptable resistance to chemicals at ambient temperature only and resistance is limited at temperatures

Table 4.4 Comparison of high-performance fibers used in impact/crash applications

	Strength	Weakness	Uniqueness
Para-aramid	Excellent Tenacity (19–25 g/d) High Modulus (550–1300 g/d) Outstanding Toughness Excellent Resistance to heat Continuous operating temp 375 °C Low elongation (1.3–4.4%) Good abrasion resistance	Low resistance to strong acids and alkalis Strength loss when exposed to: Saturated steam UV light Temp > 180 °C Combustion produce toxic gases	Solvent spun Better Cut resistance Little loss in modulus at 200 °C Strength and Modulus increase in arctic conditions. Show −ve thermal expansion Technora: good resistance to strong acids and alkali
Ultra high molecular weight polyethylene	High Tenacity (30–42 g/d) High Modulus (850–1400 g/d) Unaffected to strong acid & alkali Good light stability, abrasion and UV resistance Biologically inert High impact strength	Strength loss in strong oxidizing media Low compressive yield strength Hydrophobic in nature Prone to creep	Gel spun Low density (0.97 g/cm^3) Low melting point (150 °C) Visco-elastic material Insulator with high dielectric strength.
Thermotropic liquid crystal polymers	Good Tensile strength (12–36 g/d) High Modulus (600–1150 g/d) Low elongation (1.3–4.4%) Negligible creep High impact and high abrasion resistance Good resistance to conc acids	Strength loss when exposed to temper greater than100 °C Stable to base only at conc < 30% Poor UV resistance	Melt Spun Good low temp properties Moisture regain nearly zero Vibration dampening
Poly (p-phenylene benzo dioxazole)	High Tensile strength (42 g/d) High Modulus (1300–1950 g/d) Excellent thermal stability Good resistance to creep Good abrasion resistance Stable to alkali at room temp	Poor compressive strength Strength loss when exposed to sunlight and UV Exposure to strong acids causes strength loss	Dry jet wet spinning Highly flame-resistant (LOI 68) Coefficient of thermal expansion is negative

(continued)

Table 4.4 (continued)

	Strength	Weakness	Uniqueness
Carbon fiber	High Tensile strength High elastic modulus Good compressive strength Good electric & heat conductivity Low thermal expansion coefficient Good chemical stability	Carbon dust may cause health and electrical hazards Brittle in nature	Electro-magnetic wave shielding Self-lubrication property X-Ray permeability
Glass fiber	High Tensile strength Good impact resistance More temperature resistance Fatigue resistance	Tensile Modulus less than aramid and carbon Brittle in nature Inhaling reduces lung function	Radar transparency Good stiffness High Resistance to flame Enhanced cost advantage

above 50 °C, especially in the presence of an oxidizing agent. Also, the polyester and nylon fiber lack chemical durability due to the presence of hydrolysable groups in the backbone of fiber. However, the aromatic polyesters show greater chemical as well as heat resistance. The polycarbonates lacking in intermolecular attractions are easily attacked by solvents. The polymeric hydrocarbons are easily attacked at room temperature by chromic acid. The low intermolecular attraction and molecular inflexibility makes polystyrene rigid, but it is susceptible to chemical attacks.

The halogenated derivatives of polyethylene, polyvinylidene chloride ($–CCl_2.CCl_2–$) are the polymers with better chemical resistance and a high degree of order. But these polymers are difficult to process, and therefore copolymers with other vinyl or acrylic monomers (less than 15% by weight) are used. For example, Saran is a copolymer with vinyl chloride [24]. The fluorinated ethylene fibers offer maximum chemical inertness but are more expensive. The polytetrafluorethylene (–CF2–CF2–), PTFE fibers withstand a temperature of up to 300 °C. Poly vinyl fluoride (–CH2–CHF–), poly vinylidene fluoride (–CH2–CF2–), and other fluorinated ethylene polymers and copolymers have good chemical resistance, but their performance is limited by the lower melting points [25].

Polyetherketones are formed into fibers by high-temperature melt-spinning (at 260 °C, with short excursions to 300 °C). These fibers resist majority of chemical and high-temperature steam, except strong oxidizing acids. The Polyphenylene Sulphide (PPS) is a melt-spun fiber with excellent chemical resistance. A low second-order transition temperature of PPS (93 °C) limits its use in applications above 100 °C. The polyether-imide (PEI) has good chemical resistance and is cheap but slightly inferior heat resistance as compared to Polyetherketones (PEEK). Properties of chemical-resistant fibers and their limitations are given in Table 4.5.

Table 4.5 Properties of chemical-resistant fibers and their limitations

Name	Structure	Max service temperature	Tenacity (cN/tex)	Strain (%)	Chemical resistance	Limitations
Polyvinylidene chloride, PVDC	$(–CCl_2.CCl_2–)$	100–115	20	15–30	Better	Difficult processability
Polytetra-fluorethylene, PTFE	(–CF2–CF2–)	290–300	14	20	Excellent	Expensive
Poly vinyl fluoride, PVF	(–CH2–CHF–)	150	19–39	15–30	Good	Low melting point
Poly vinylidene fluoride, PVDF	(–CH2–CF2–)	150	43	25	Good	Low melting point
Polyether ketones, PEEK		260	61	19	Good, except strong oxidizing acids	High-temperature melt spinning
Polyphenylene sulphide, PPS	$(C_6H_4S)_n$	190	18–23	12–16	Excellent	Notch sensitive
Polyether-imide, PEI	$(C_{37}H_{24}O_6N_2)_n$	200		30	Good	Inferior heat resistance

4.5 Heat Resistant Fibers

The heat/temperature resistance plays a basic role, while selecting a fiber for high-temperature applications. Most of the conventional fibers are degraded by heat/high temperature (below 300 °C) depending on the fiber composition, exposure time, and atmospheric conditions. The heat resistance of a fiber is generally measured in terms of its continuous operating temperature. When used at temperatures higher than the operating temperature, fibers may survive but the high heat start fiber degradation, leading to reduction in the mechanical performance of the fiber and ultimately destroy its integrity. The heat resistant fibers should not be confused with the flame-retardant fibers, but some fibers may offer both flame and heat resistance.

A most common example of heat resistant fibers is the use in firefighter clothing, oil and gas industry workers, etc. to protect them from thermal exposures (e.g., flame, hot surface, radiant heat, steam, molten metal substances, hot liquids, etc.). The thermal insulation of these clothing is strongly controlled by various factors like fiber, yarn, fabric properties, and clothing features. Another factor that needs to be considered in these clothing is the comfort performance of the clothing. Therefore, the thermal protective clothing should be designed in such a way to provide best thermal protection and also comfort to the wearer. The thermal protective clothing is composed of three main components, i.e., shell fabric, thermal liner, and moisture barrier [26].

The shell is generally produced from a plain-woven fabric using flame-retardant fibers like PBI, aramid, or a compatible blend. The thermal liner is a combination of woven fabric (face) and a batting. The face fabric is produced from flame-retardant fibers and sewn with the batting. The batting is produced from long flame-retardant fibers using a nonwoven technique and bonded either by chemical, mechanical, heat, or solvent treatments. Commercially used batting fabrics (needled felt) are Nomex, Kermel, semi-carbon, and polysulfonamide. The thermal liners commonly used are either combination of Kevlar/Nomex batting and aramid woven fabric (plain) or spun-laced nonwoven fabric. Some of the popular commercial thermal liners are AraliteGold, OMNIQuilt, Flame Quilt, and Quattro-tech.

Asbestos is a mineral fiber existing in nature and is heat resistant inherently, however it is a health hazard due to extreme fineness. The glass fibers offer heat resistance up to 450 °C, but these fibers have poor aesthetics and are difficult to process. The dominant heat- and flame-resistant fibers are the aramids and arimids. The most commonly used fiber, with good textile properties, is the meta-aramid produced with commercial names of Nomex (Dupont) and Conex (Teijin) [27]. The m-aramids can resist temperature of up to 250 °C for 1000 h with only 35% deterioration in the strength. At temperatures above 400 °C, the aramids form char and survive short exposures up to 700 °C. This char is tough acts as a thermal protective layer, making it a good candidate for fire protection applications [28].

The poly (p-phenylene benzobisoxazole), PBO is another heat resistant aromatic fiber made from linear polymers. It has remarkably high thermal stability (thermal degradation onset up to 600 °C). owing to stiffer chains, PBO is considered as the most thermally stable commercial fiber available currently. Additionally, these fibers have very high flame resistance and good resistance to creep, chemicals, and abrasion, but exhibits poor compressive strength. Para-aramids, (Kevlar, Technora, Twaron) are also used for thermal protection, either alone or in blend form. They have the additional property of high degradation temperature, high strength, and stiffness.

The P84® polyimide fibers are made of poly[4.4‘-diphenylmethane-co-tolylene benzophenotetra-carboxylic-imide] and manufactured by Evonik. The base material for P84® fibers is composed of aromatic backbone units only and is highly non-flammable with an LOI of 38. The fiber offer outstanding chemical, thermal and flame-retardant properties as compared to m-aramid. These fibers are preferred for applications including protective clothing, heat insulation, high-temperature filtration, etc.

Kermel is a polyamide-imide fiber (categorized in the meta-aramid family), with no melting/burning at extremely high temperatures, making it an ideal choice for heat and flame-retardant textiles [29]. Additionally, it also exhibits good mechanical performance and chemical resistance. The salient features of this fiber include lifelong colourfastness (due to solution dyeing), no pilling, lightweight, comfort, minimal shrinkage, etc.

PBI (polybenzimidazole) is an organic high-performance fiber originally developed by Celanese for NASA Apollo space program. The fiber has inherent flame resistance properties along with heat and chemical stability. It does not burn, melt, or aid in flame propagation [30]. Currently, PBI Performance Products is the sole producer of this fiber globally. The PBI fibers have a long chain aromatic polymer as backbone with recurring imidazole groups as repeat units in the polymer backbone, that results in high glass transition temperature (425 °C) with no melting.

The heat resistant fibers are also produced from thermoset polymers by extruding the partially cured or uncured resin with subsequent cross-linking. Such fibers advantageous in terms of high flame resistance and minimal smoke emission with no toxic gasses in flame. The Kynol novoloid (phenol aldehyde) is the earliest example of these fibers and exhibits remarkable resistance to solvents, acids, steam, or other chemicals in addition to excellent thermal resistance. Basofil is a melamine-formaldehyde-based fiber with a service temperature of 190 °C.

4.6 Flame Retardant Fibers

The flame-retardant (FR) fibers need to be distinguished from the temperature-resistant fibers, although some fibers fall in both the categories. The flame retardancy is generally determined in terms of Limiting Oxygen Index, and the fibers having LOI greater than 25 are termed as flame retardant. It means that at least 25% oxygen must be present in atmosphere for ignition of such fibers. Some of the fibers are inherently flame retardant while others can be made FR by adding/applying a flame-retardant finish [31]. The flame-retardant chemicals are either added to the polymer solution before or during extrusion process. Additionally, impregnating the fiber/fabric adds flame retardant properties directly to the fabric (e.g., FR treated cotton fabrics).

The inherently flame-retardant fibers include m-aramid (Nomex) that was initially developed for fighter pilots, astronauts, tank crews, military personnel, and certain industrial applications. The aramid fibers do not have any FR elements/groups, but their FR behavior is due to the chemical structure (as it does not break into combustible fragments). Some m-aramid fabrics shrink and break open under heat and are therefore blended with 5% Kevlar fibers. Teijin introduced a FR denim (Xfire DENIM), like aramid fiber for firefighting uniforms. It is made of Teijinconex meta-aramid fiber [32].

The flame-retardant cellulosic fibers are categorized into two types, i.e., silica containing and phosphorus-containing [33]. The commercial fiber of first type is VISIL® (Sateri, Finland), that is permanent FR fiber owing to the high polysilicic acid complex content (30–33%) added during manufacturing. It does not melt/flow when in contact with flame and no toxic fumes are emitted. Its other advantages include blending with natural fibers, environmentally benign manufacturing, and bio-degradability. The example of second type is Lenzing FR® (Lenzing), which is a regenerated cellulosic fiber-containing organophosphorus additives introduced during manufacturing. It forms char when in contact with flame and offers protection from flame and heat. It can be blended with other inherently FR fibers like modacrylics and aramids. Common FR fibers, their properties and applications have been compared in Table 4.6.

4.7 Conductive Fibers

The conductive fibers are widely used for smart textile applications like sensors, heating element, static dissipation, EMI shielding, etc. The term smart textile describes the textile materials that can sense, react or adapt to some stimuli (internal or external) and are produced by integrating smart functions in textiles (mostly conductive fibers circuits are woven into fabric) [34]. To incorporate conductive fibers in textiles, it is desirable that these fibers should be strong and flexible, in addition to the conductivity. In terms of clothing comfort, it is required that the fabric should have properties like stretch ability, shear, and soft handle (fabric feel).

The conductive fibers consist of a blend of less-conductive/nonconductive substrate, that contains either conductive elements or coated with conductive elements [35]. The intrinsically conductive materials are directly spun into directly yarn or blended with/wrapped over textile fibers, e.g., conductive metals like stainless steel, copper, aluminum, nickel, titanium, etc. The most common example of blended conductive yarns is Bekaert Bekinox® (fine stainless-steel fibers) blended with different staple fibers to get anti-static yarn. The concentration of Bekinox® in the blend depends on the nature of fiber and requirements of the applications. Silk organza is the example of wrapped conductive yarn (thin copper foil is wrapped over silk fiber).

Table 4.6 Properties of flame-retardant fibers

Fiber	Common name	LOI	Tenacity (cN/Tex)	Other	Applications
FR viscose	Lenzing FR	28	16–24	El = 14–22	Electrical arc (at temp up to 10000 °C)
FR polyester	Trevira CS				Upholstery, drapes, blinds, seat cover, wall coverings, partitions, curtains, beddings, etc.
m-aramids	Nomex, Conex	28–31	206		Racing suits for driver and crew, Flight suits used by fighter pilots, EMS (emergency medical service)
Polyimide	P84, Kermel	38	38	El = 30 De = 1.41	Kermel A90 is used for military applications, flight suits and gloves, riot suits, fire fighter clothing, etc.
Polybenzimidazole	PBI	> 41	24	El = 28.5 De = 1.43	Aircraft furnishing, escape suits for astronauts, fire-fighting suits
Poly(p-phenylene benzo bisoxazole)	PBO, Zylon	68	370	El = 3.5 Tm = 650	Electronic insulation, military and aerospace applications
Melamine formaldehyde	Basofil	32	20	El = 15–18 MR = 5	Racing garments, fire fighter clothing, non-woven inter liners for gloves, jackets, etc.
Novoloid	Kynol	30–34	12–16	El = 30–60 MR = 6	Protective apparel, safety accessories, flame barriers, liners for upholstery, etc.
Poly phenylene sulphide	PPS	40	43	El = 34.5 Tm = 285 De = 1.34	High-temperature electrical applications
Oxidised acrylic	Panox, Pyron	55	20–30	MR = 10	Insulation, home furnishing, air craft brake, friction applications

(continued)

Table 4.6 (continued)

Fiber	Common name	LOI	Tenacity (cN/Tex)	Other	Applications
PTFE	Teflon	95	9–60	MR = 0	Flame retardant, thermal insulation, fire curtain, smoke barrier

El: elongation (%), De: density (g/cm^3), MR: moisture regain (%), Tm: melting temperature (°C)

Table 4.7 Advantages and limitations of intrinsic and extrinsic conductive fibers

	Advantages	Limitations
Intrinsic conductive fiber	High conductivity and mechanical resistance Low weight High fatigue resistance	Difficult to integrate into woven/knitted fabrics Health hazards (carbon fiber) Low flexibility
Extrinsic conductive fiber	High conductivity and mechanical properties	High manufacturing cost High weight Washability (surface coated conductive fibers)

Another approach is to produce conductive yarns by using conductive fillers. It is specifically used for thermoplastic polymers (e.g., PE), the dope is charged with conductive fillers and then spun to get conductive yarns. It is also accomplished by the deposition of conductive particles on the surface of yarns [34]. The conductive particles (e.g., carbon) are dispersed in polymer melt before extrusion or deposited (e.g., nano-silver) on fiber surface. It gives an excellent control of static electricity but these conductive yarns are usually black in appearance and limits the use in industrial fabrics and apparel [36]. Other techniques of producing conductive textiles include padding of electrolyte solution on yarn, by printing or lithography [37]. The advantages and limitations of intrinsic and extrinsic conductive fibers are given in Table 4.7.

A fully conductive fiber is supposed to suffer from surface modification, while a core conductive fiber is generally used to avoid the surface modification.

4.8 Fibers for Military/Defense Application

The military forces are widely using textiles for protection against ballistic impact, chemical protection, flame resistance, thermal protection, communications (e-textiles), etc. The fibers for communications, chemical, thermal, and flame protection have been discussed earlier. Ballistic protection is the ability of a material to stop bullets or small object by absorbing energy locally and spreading it out quickly and efficiently without injury to the wearer. Generally, it is considered that ballistic protective material has minimum blunt trauma (back side deformation). It could be said that the protection against bullet means to stop bullets in minimum accessible distance of the vest. The ballistic protection is achieved by protective body armor. This protective armor absorbs impact energy from fire arms, projectile, short gun projectiles, and hand guns [38, 39].

Ballistic protection has become a necessity of every security individual due to advancement in the ballistic threats. Different materials and techniques have been used by human beings for ballistic protection throughout its history, as per demand and availbility of materials. The history of protection starts from the animal skin to wood, steel/metals, and then different types of fibers. Some recent trends involve the ballistic protection using nanomaterials. In the era of swords, the warriors used to wear metal jackets for protection. The importance of shielding from ballistic projectiles gained importance in the twentieth century.

The English produced shield design for body parts (including having padded neck and ballistic vest) commercially from materials like cotton and silk [40]. From 1914 to 1918, different types of body armors (metal plates for front and back) were introduced. Japanese used first soft body armor made of silk fiber, but the idea was not successful commercially due to high cost of silk [41]. Flake jacket made of nylon, with steel plate inside, was new revolution in field of protection during World War II. These jackets were heavy and rarely used for military purpose. A new generation of fibers (para-aramid) was introduced in 1965 to offer better protection against bullets.

Further advancements in technology led to the use of composite material for ballistic protection in the recent years. Composites have gained attraction due to its characteristics e.g., light weight, high strength to weight ratio, corrosion resistance, etc. The use of composite materials in ballistic protection has introduced concept of hard and soft body armors, varying in structure and offering different levels of protection accordingly. Concept of composite plates, high-performance synthetic fibers and ceramic backing have been invented for new armors [40].

The ballsitic armor is defined to be a protective covering used to avoid damage from being inflicted by a high-speed projectile, usually during combat [42]. Applications of ballistic armors are wide spread and include personal body armor, vehicle armor, ballistic helmets and boots, small arms protective inserts, etc.

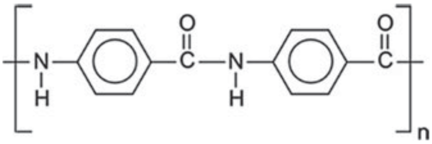
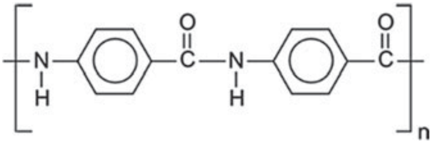
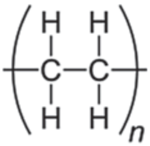
The armors being used these days have two major sections, i.e., Soft Armor Panel (SAP) and Hard Armor Plate (HAP). SAP is made up of low-density fiber, e.g., para-aramid, ultra-high molecular weight polyethylene, zylon, nylon, etc. [43]. The para-aramids are the most widely used for body armor, while others have great potential for ballistic protection, but needs to be investigated yet [44–47]. The SAP is flexible in nature and can be tailored to conform to the body contour of the person wearing the body armor. Soft body armor only is manufactured to protect police officer from handgun bullet commonly.

However, for military, hard body armors (HAP) are designed to stop fragments from the explosion as well as a bullet from a rifle and these are normally large and visible. HAP is made from hard ballistic materials like compsoites, ceramics, and/or metal plates to stop high-energy projectiles. With the advancement of technology, the metal plates are not being preferred for HAP, and have been replaced by the composite materials.

A number of factors are considered while designing a ballistic helmet. These factors are not limited to ballistic protection but also include its fit, comfort, and weight. With increase in protection level, the helmet weight is increased, and its comfort maybe compromised (owing to burden for wearer and its heat retention). This lack of comfort urges the soldiers to take off the helmets and get themselves into danger. Therefore, the combat helmets are subjected to a series of testing including both the ballistic and non-ballistic tests. The ballistic protection ad bullet penetration are assessed in ballistic testing, while non-ballistic tests assess pad compression durability, helmet compression resistance, and coating adhesion durability.

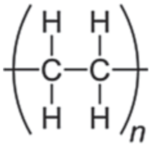
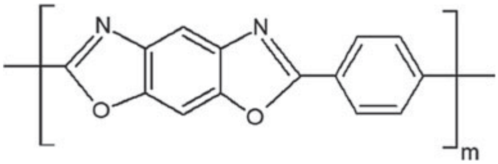
Dupont provided Kevlar fiber and in terms of ballistic helmets, it has been used in the Personnel Armor System (helmets). For just about special application Twaron (soft Aramide) is likewise used as bulletproof fabric. Twaron is a light para-amid fiber. It is really similar to Kevlar having a high impact property. Spectra fiber is likewise applied as reinforcement in existing combat helmets. Compression Molding Technique is applied for combat helmet manufacturing. The international manufacturers of combat helmets include are OPS-core Gentex, United States, Team Wendy, Cleveland, Ohio, and HHV (Hard head veterans) United Kingdom. The fibers used for ballistic protection include p-aramid (Kevlar, Twaron, etc.), Ultra High Molecular Weight Poly Ethylene (Dyneema, Spectra, etc.) and PBO (Zylon, etc.). Table 4.8 gives the properties of commercial fibers that are commonly used for the ballistic protection.

Table 4.8 Properties of fiber commonly used for ballistic protection

Commercial name	Chemical name	Properties
Kevlar by Dupont	p-aramid	 Low density and high tensile strength Flame retardant with self-extinguishing properties Low thermal shrinkage and excellent dimensional stability High modulus due to low elongation High toughness (work-to-break) Excellent cut resistance
Twaron by Teijin	p-aramid	 Low flammability High decomposition temperature (500 °C) Neither burns nor melts Highly crystalline and offers good chemical resistance Excellent energy dissipation properties
Spectra by Honeywell	UHMWPE	 Low density (less than 1 g/cm^3) Specific strength 40% greater than aramid Very high initial modulus Excellent vibration damping and flex fatigue Enhanced tear and abrasion resistance

(continued)

Table 4.8 (continued)

Commercial name	Chemical name	Properties
Dyneema by DSM	UHMWPE	 Low density (less than 1 g/cm^3) High strength to weight ratio Flame retardant and self-extinguishing Faster dissipation of shock waves, and high energy absorption characteristics Biologically inert
Zylon by Toyobo	PBO	 Excellent strength-to-weight ratio (better than aramid) Excellent heat resistance and dimensional stability Good chemical resistance Exceptional ballistic properties

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Chapter 5
Fibers for Sports Textiles

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Abstract Sports textiles mainly consist of both sportswear and sports equipment, because different natural and synthetic textile-fiber-based products are used in both categories. Sportswear has a vast range of wearing items which can be classified as sports-inspired wear, outdoor wear, performance wear, and leisure wear. Different functional fibers are used in sportswear to get desired results having different properties like comfort, thermal conductivity, cold and heat indices, and stretch and recovery. Similarly, there is a vast range of sports that include hiking, snow sports, cycling, mountaineering, hockey, baseball, squash, and sailing, using a range of sportswear for both fashion and functionality. The outfits and equipments used in these sports are also composed of different functional and high-performance fibers like polyester, acrylic, nylon, spandex, polyolefin, aramid, and carbon. For various attires' manufacturing, synthetic fibers and their blends with different natural fibers, i.e., cotton, hemp, bamboo, silk and wool, are also used. The advanced countries are using their strengths in the field of materials and engineering technologies to develop new functional fibers. Now a days, composite fibers and fiber reinforced composite material based light weight products are used in sports goods with improved strength and functionalities.

Sportswear has a wide range of wearing items that can be classified as sports-inspired wear, performance wear, and outdoor wear. Leisure apparel has great importance in the sportswear. The significant grown interest in active indoor and outdoor sports, and leisure pursuits resulted in a substantial increase in the consumption of textile fibers and fabrics in sports for two decades. There are so many factors due to which the interest is rising, including the growth of indoor and outdoor sports facilities,

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increased considerations of well-being and good health, increased leisure time, and functional sportswear [1].

5.1 Sportswear Sectors

There is a vast range of outdoor sports include football, tennis, hiking, snow sports, cycling, mountaineering, and sailing with a wide range of leisurewear for both fashion and functions. The main stakeholders of the textile industry are based on these product manufacturers who use the latest technologies. They use the most updated processes and advances in high-performance fibers and high-functional materials to complete the requirements of various types of consumers and market needs. A massive increase in female participation in professional and outdoor sport is also a high impact factor for the new trends in sportswear. In the global market, the volume for each product may vary according to the type of end-use applications. High-value products always stay at the top of the price scale with low volumes, and these products are very particular products in which quality, performance, and design are major determining factors. This segment of the textile industry is growing at a higher rate. Different textile materials solely or with a combination of other flexible materials are used to develop sports footwear, and sportswear for other types of sports, *e.g.*, football clothing, athletic clothing, skiing clothing, and protective clothing [2].

The largest market in the world for sportswear is the United States, which comprised the one-third of the overall global sale and China is 2nd largest market with a 10% share. The economic growth of BRIC (Brazil, Russia, India, and China) is significant in recent years, and these countries have a powerful effect on the trade of sportswear [3].

5.2 Fibers Used in Sportswear

Fibers have a wavy structure that is responsible for many characteristics of the fabrics that have a significant value for the performance of sportswear and functional clothing. Sportswear is a combination of multiple attributes; for example, it gives functional support, protects the athlete from injury, enhances performance, promotes sporting activity, and offers the wearer comfort. The most crucial factor that contributes to the comfort of the wearer is moisture and thermal balance which results in proper micro-climate of the skin. Natural silk fiber has long been a valuable commodity. After the discovery of Nylon fiber, Du Pont Co. started its production in 1939 [1]. Both natural and synthetic fibers are used in sportswear. The details of a few of these fibers are discussed in the following sections.

5.3 Natural Fibers

5.3.1 Cotton

Cotton is characterized as a white stringy strand covering seeds collected from the cotton plant [2]. It is gathered from the plant by handpicking or by machine picking. Cotton is the most significant fiber in the material world. Various assortments of cotton are being utilized in the sports industry [4]. Cotton fiber has large amorphous portion and this is why the air can be in and out through cotton fiber. So, the fabric made by cotton fiber is quite comfortable to use.

5.3.2 Hemp

Hemp is one of the long-lasting fibers in terms of performance. A linen-like drape, hemp is commonly used separately or in combination with other fibers in some outdoor products [5]. Ropes are one of the most important pieces of gear for mountaineering and one of the first to be used to secure climbers. Originally they were crafted from natural fibers such as hemp or manila ropes [6]. Hemp is used to make a variety of commercial and industrial products, including rope, textiles, clothing, shoes, insulation, and biofuel.

5.3.3 Bamboo

Bamboo is one of the world's fastest-growing plants, growing in around three months to a maximum height, reaching maturity in 3 and 4 years and spreading rapidly over large areas. The fiber origin is currently being advertised as an eco-green-sustainable fiber, due to the relatively fast-growing and the ability to grow without fertilizers or pesticides. Bamboo fabric is soft, durable, with properties that are moisturizing and insulating. It also has some antibacterial properties and is resistant to odors. For items such as casual sportswear, base layers, t-shirts, and yoga clothes, bamboo fiber is commonly used [7].

5.3.4 Wool

Wool is a protein-based fiber that usually comes from sheep and other animals, including goats and llamas. Wool and its blends can be used in knitted, woven, and felt constructions as well as accessories throughout the sports layering process. [8]. The amount of crimp corresponds to the fineness of the wool fibers. A fine wool like Merino may have up to 40 crimps per centimetre (100 crimps per inch), while coarser wool like karakul may have less than one (one or two crimps per inch).

5.3.5 Silk

Silk is derived from silkworms that live on mulberry leaves in large trays, usually indoors. This sort of silk is called cultivated and is produced on large farms owned by industry. The silkworms are bred humanly, which means that the wild silk cocoons are harvested using natural methods only after the cocoon spontaneously emerges from the moth [9]. Several kinds of wild silk, produced by caterpillars other than the mulberry silkworm, have been known and spun in China, South Asia, and Europe since ancient times. E.g. production of Eri silk in Assam. However, the scale of production was always far smaller than for cultivated silks. The process of silk production is known as sericulture. Silk has a smooth, soft texture that is not slippery, unlike many synthetic fibers. Silk is one of the strongest natural fibers, but it loses up to 20% of its strength when wet.

5.4 Synthetic Fibers

5.4.1 Polyester

In 1993, cooperation between Patagonia and Malden Mills led to the early development of recycled polyester fiber (from Wellman Inc.) for use in Synchilla fleece made from plastic soda bottles that diverted waste from landfills. PCR filament yarn was later made from 30 to 50% post-consumer products (containers, polyester uniforms, tents and clothing) for linings and shell fabrics. At the end of life, the fabric could be recyclable if it consists of one form of fiber. Consumers may, in theory, return a polyester garment for transmission to a processor to be made into fiber or downgraded to other plastic types. Polyester is a synthetic petroleum-based fibre, and is therefore a non-renewable carbon-intensive resource. Polyester fibers are sometimes spun together with natural fibers to produce produtc with blended properties. Cotton-polyester blends can be strong, wrinkle- and tear-resistant, and reduce shrinking. Synthetic fibers using polyester have high water, wind and environmental resistance compared to plant-derived fibers. For sportswear, polyester is favored due to its lightweight, inexpensive processing, slow dyeing, longevity, easy-care properties, fast drying, hydrophobic for nature, and wicking. However, the hydrophilic coating can be given to the polyester filament fabrics. Therefore, with its hydrophobic center and hydrophilic coating, polyester fiber-based fabrics allow it to wick moisture away from its skin-to-outer surface contact with the environment. Polyester is often combined with other natural fibers to extract its benefits to maintain moisture control and longevity.

5.4.2 Spandex

The typical elastomeric fibers classification process is based on elastic elongation and chemical composition. Elastomeric fibers based on polyurethane show the extensive range of elongation and elastic recovery efficiency. Unlike spandex, this type of fiber contains more than 85% segmented polyurethane formed by a diisocyanate reaction with polyethers or polyesters and subsequent polyurethane unit cross-linking. Spandex is used in various sportswear because it is lightweight and provides the ability to move freely [10, 11]. The elasticity and strength (stretching up to five times its length), of spandex has been incorporated into a wide range of garments, especially in skin-tight garments. A benefit of spandex is its significant strength and elasticity and its ability to return to the original shape after stretching and faster drying than ordinary fabrics. For clothing, spandex is usually mixed with cotton or polyester, and accounts for a small percentage of the final fabric, which therefore retains most of the look and feel of the other fibers.

The major categories in which spandex fiber is used are; (a) Athletic/aerobic/exercise equipment (b) Socks and tights (c) Tracksuits and tops (tennis/polo) (d) Cross-country running suits (f) Professional swimwear (g) Running jerseys and shorts.

5.4.3 Acrylic

Acrylic fabric is lightweight, warm, and soft to the touch. Acrylic fiber is usually blended with natural wool fibers or used to mimic wool not for its properties. There are now at least 30 different acrylic fibers [12]. Many of them, including Acrilan, Courtelle, Creslan, Dralon, Zefran, Verel, Crylor, etc., are already well known [13]. Similarly, in Modacrylic fibers the fiber-forming material is any long chain of a synthetic polymer composed of less than 85%, but of acrylonitrile units at least 35% by weight [13, 14].

5.4.4 Nylon

Nylon 6 and Nylon 6,6 are the most common forms. Nylon 6 is made of caprolactam, which is produced through a series of reactions using coal tar materials. The resulting filament is not going to be strong enough and has very high extensibility. Monofilament is of great strength and smoothness single, strong strand of filament. In the form of monofilaments, approximately 90% of all polyamide fibers are processed. In car tires, fishing ropes and networks, gliders tow ropes, sailing clothes, conveyor belts, carpets, tapestries, draperies, nylon fibers are used [15, 16].

5.4.5 Polyolefins

The two most important polyolefin fibers are polypropylene and polyethylene. Polyethylene has a simple, linear chain structure consisting of a backbone of carbon and small side groups of hydrogen. Such a structure makes crystallization simple. There are three common grades of polyethylene. Polyethylene with low density (LDPE), polyethylene with high density (HDPE) and polyethylene with high molecular weight. It is the type of ultra-high molecular weight polyethylene used to make high modulus fibers. The UHMWPE fibers are high strength and high-modulus fiber, which give them commercial importance [17]. Fibers of less than 0.3 dTex (denier) thickness are considered microfibers. Because of their high surface area compared to ordinary fibers, microfibers find their use in air filters, dust wipes, etc. Polyester and nylon are currently used in the production of microfibers. Yet grades of rayon and acrylic goods micro-denier' are on the horizon. As long as micro fiber technology has been around, ultra-micro fiber technology has existed as well. These are fibers that are less than 0.3 dtex, especially within the 0.1 dtex range. Such fibers can be made using several different processes, all requiring the breaking of a larger fiber into many smaller ones [18]. Ultra-fine linear density (less than 0.1 dtex/f), fineness lower than the finest silk. It has a very soft and luxurious hand with a touch of silk or suede. Microfibers dry in one-third of the time as compared with the ordinary fibers. Microfibers are friendly to the environment [19, 20].

5.4.6 Advanced Thermo-Regulation Fibers

Thermo-°Cool® is a combination of channeled shaped fibers, and hollow fibers create additional fiber spaces that enable better air circulation and significantly improve the evaporation capacity of the product. Outlast: The fiber includes Outlast PCM (phase change materials) [21]. These fibers are spun into yarns and are intended for those fabrics that are worn next to the skin. The Outlast® technologies uses the PCM that absorb, store and release the heat for optimal thermal comfort. Outlast® technology has the ability to continually regulate skin's microclimate. As the skin gets hot, the heat is absorbed, and as it cools, that heat is released. Similarly, Outlast® Technologies, commonly referred to as Outlast, also develops and sells phase change materials (PCMs) in the United States and internationally. Outlast offers Thermocules, a microencapsulated phase change materials, which are incorporated into fabrics and fibers for absorbing, storing, and releasing excess heat. The company's products comprise temperature regulating textiles, fabrics, fibers, and knits. Its products are used in outdoor sports, bedding, apparel, and footwear applications.

5.4.7 Carbon Fiber

Carbon fibers (alternatively CF, graphite fiber) are fibers about 5–10 micrometers in diameter and composed mostly of carbon atoms. Carbon fibers have several advantages including high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance and low thermal expansion. These properties have made carbon fiber very popular in aerospace, civil engineering, military, and motorsports, along with other competition sports. The carbon (diamond-type) has a covalent structure and is an extremely hard material. Buckminster Fullerene or Buckyball, with a molecular composition such as C60 or C70, and carbon nanotubes, are the latest additions to various forms of carbon. Carbon nanotubes (CNTs) are short, thin carbon atom cylinders structured in a graphic lattice structure. These contain carbon nanotubes that are single-walled and multi-walled.

Nevertheless, it is vital to study the basic structure and characteristics of graphite to understand these aspects of carbon nanotubes [22]. These are usually between 5 and 20 nm in diameter and between 1 and 100 μm in length, which gives them a very high aspect ratio [23].

5.4.8 Aramids

In 1965, Stephanie Kwolek, a DuPont research scientist, discovered that, under certain conditions, para-aminobenzoic acid could be polymerized and solubilized to form a spinnable rigid-rod liquid crystalline solution. This finding can be known as the beginning of aramid fibers. The polymer obtained through the reaction of p-phenylenediamine and terephthalic acid was later found to be stronger. It should be noted that researchers at Monsanto made important contributions, but Monsanto chose not to sell an aramid fiber [24]. Aramids are mostly available in two types i.e. para-aramid and meta-ramid. Aromatic polyamides were first introduced in commercial applications in the early 1960s, with a meta-aramid fiber produced by DuPont as HT-1 and then under the trade name Nomex. It has excellent thermal, chemical, and radiation resistance for a polymer material. In 1973 DuPont was the first company to introduce a para-aramid fiber, which it called Kevlar, to the market; this remains one of the best-known para-aramids and/or aramids. In 1978, Akzo introduced a similar fiber with roughly the same chemical structure, which it called Twaron. Due to earlier patents on the production process, Akzo and DuPont engaged in a patent dispute in the 1980s. Twaron subsequently came under the ownership of the Teijin Company. In 2011, Yantai Tayho introduced similar fiber which is called Taparan in China.

5.5 Properties Required in Sportswear

Clothing is a basic human need that protects the body from environmental and climate hazards. In technical terms, features are required that relate to the functionality rather than just the basic requirement. High performance is a desirable attribute that requires calming activity for professionals. High-performance textiles cover a wide range of textiles that focus on the end-use breath of operation. These include different categories such as textiles for personal protection, textiles for the protection of medical health, and textiles for the protection of sportswear. Protective textiles are necessary to fulfill the practical clothing specifications laid down in the relevant regulations. From using natural fibers, there has been a shift from using more synthetic fibers for high-performance textiles [25]. Following major properties are required in the fibers for sportswear applications:

5.5.1 Comfort

The term comfort is defined as "a lack of discomfort" or "a neutral state as compared to a more active state." Comfort can also be described as an enjoyable state of sensory, psychological, and thermo-physiological harmony between humans and their climate. The ease of the wearer is linked to the wearer's sensational discomfort when the skin is touched by part or with the whole garment. These include sensations of tactile, thermal, and moisture. For functional operation and quality, movement is essential. Clothing designs, therefore, need to integrate versatility features. The wearer's physiology and the role to perform are vital to the wearer's safety and comfort [17].

5.5.2 Temperature and Wind

There have been several attempts to include the physical weather parameters (temperature, wind, relative humidity, and radiation) in a single climate chart. Windchill is also a combination of ambient temperature and wind speed. Windchill can be used to predict the risk of exposed skin freezing and to predict a decrease in manual dexterity. As a cold injury risk estimator, the wind chill index is part of an ISO standard (11079, 2007). For heat, by increasing convective and evaporative heat loss, the wind has a cooling effect [26]. High humidity increases air thermal stress and does not matter to the cold. Leithead and Lind (1964) published a list of all fatal heatstroke events in the United States. A straight line beyond which the casualties occurred can be drawn. The combination of ambient temperature and relative humidity is referred to as the United States' heat index (HI) and Canada's humidex [27, 28, 29].

5.5.3 Sustainability

Sustainability is a broad discipline, giving insights into most aspects of the human world from business to technology to environment and the social sciences. Sustainability is one the newest degree subjects that attempts to bridge social science with civic engineering and environmental science with the technology of the future. When we hear the word "sustainability" we tend to think of renewable fuel sources, reducing carbon emissions, protecting environments and a way of keeping the delicate ecosystems of our planet in balance. In short, sustainability looks to protect our natural environment, human and ecological health, while driving innovation and not compromising our way of life. It focuses on meeting the needs of the present without compromising the ability of future generations to meet their needs. The concept of sustainability is composed of three pillars: economic, environmental, and social—also known informally as profits, planet, and people.The sustainability movement has contributed to a reduction in the use of petroleum-based materials to partially plant-based products. For example, in protective clothing, such as Sorona fabrics, plant-based fibers and fabrics are used. By 2030, the climate impact of the apparel industry alone is forecasted to almost match today's annual US greenhouse gas emissions, emitting an equivalent of 4.9 gigatonnes of carbon dioxide. Choosing recycled polyester, local or organic cotton and water-saving fibers such as Tencel and hemp, has a lower environmental impact. It also sends a clear message to producers, that there is a high demand for eco-friendly products. In order to make a positive environmental impact, recycling, shifting to renewable energy, eco-friendly processing methods, smarter design, and efficient consumption methods are crucial.

5.5.4 Cold Weather Sports Clothing

Outdoor sports are often carried out under harsh environmental conditions. In Antarctica, the lowest temperature ever recorded on Earth was -89.2 °C. Professional athletes and an increasing number of amateur athletes, either in polar or mountain regions, are subjected to climatic conditions with very low temperatures. The sportswear must offer the best possible comfort in addition to providing full cold protection. The main challenge is to preserve the clothing's thermal insulation in all climatic conditions, especially in the presence of wind [1].

5.5.5 Moisture Production and Transport

One of the most important factors to consider in the cold is the development of the body's moisture and how this moisture is transferred through the layers. The condensation of water vapor in the clothing and the accumulation of this condensation will determine the clothing's thermal insulation, as the water's thermal conductivity is about 25 times greater than that of air.

Sensitive suddenness is produced by the sweat glands and depends on factors such as age or fitness level. The amount of water vapor transferred through the body depends on the relative humidity of the skin and, more specifically, on the disparity of water vapor pressure between the skin and the atmosphere, reaching approximately 20–25 g/h for a person under standard environmental conditions (20 °C, 50% RH) [30].

5.5.6 Thermal Insulation

As air is one of the strongest insulators, the main goal of cold defense clothing is to absorb as much air as possible between the various layers of clothing and to prevent air movement and transfer of heat between the layers of skin. A mixture of three or four layers is the most common concept in cold weather sports clothing. These layers consist of a skin-friendly base layer (underwear), one or two middle layers, mainly used for thermal insulation and an outer shell for weather protection (i.e., wind and rainfall). The number of (middle) layers can be increased when required in icy conditions; we can see on the market clothing concepts consisting of six or even seven layers [25].

5.5.7 Mechanical Properties

These are some mechanical properties that can affect the performance of fibers as well as sportswear. A small diameter is relative to its size of a grain or another microstructural unit. This helps in a bulk form to achieve a higher fraction of the theoretical strength than that possible. This is a direct consequence of the so-called size effect, whereby the smaller the scale, the lower the probability of getting a critical scale imperfection that would consequence in material failure. Therefore, its strength decreases even for material in its fibrous form as its diameter increases. A very high degree of flexibility that is always a hallmark of a high-modulus material with a small diameter. This versatility allows for the use of a range of techniques for producing composites with these fibers that are reinforced with fabrics, chains, cords, and threads. A high aspect ratio (length/diameter) that allows transferring a very large fraction of the applied load into the rigid and robust fiber in a fiber-reinforced composite through the matrix. A fibrous material has the most distinctive characteristic of having properties that are strongly biased along its length. A fibrous material having high aspect ratio and may be highly flexible. It is possible to produce such a versatile fiber into yarn, which in turn can be braided, knitted, or woven in very complex shapes and forms [31].

5.5.8 Stretch and Recovery

Because of the increased comfort demand, the stretch fabrics have become a standard in sportswear apparel. Elastomeric structures are used to improve comfort of the fabrics in sportswear. The market is becoming more attractive for tighter compression garments. The natural movement of the body stretches the skin by 10–50% and the strenuous movement in sports would require less resistance from clothing and rapid recovery.

5.6 Fibers for Sports Equipment

The sporting goods industry in the later decade of the twentieth century was a boom to the advanced composites market. Today, in seven of the ten most popular outdoor sports and recreational activities, composites are used in items. In skis, fishing rods, bowling balls, tennis rackets, spars/shafts for kayak paddles, windsurfing masts and frames, hockey sticks, kites, and bicycle handlebars, glass and carbon-reinforced composites (alone or in combinations with other fibers) tend to substitute wood and iron. Market research firm Lucintel (Irving, TX, US) predicts a retail value of US$ 5 trillion in the international sporting goods sector, taking in US$ 110 billion/year alone in the United States. Bicycles remain the highest-profile market for the use of composites. In other words, the use of composites in bikes is important as it allows for significant weight savings, so the less material used is better. The challenge facing by the bicycle manufacturing industry is the lack of strictly enforced standards for the design and manufacture of carbon fiber composite bike frames. In the watersports market, there has recently been significant activity, particularly in the area of stand-up paddleboard fins. Composite World has covered many applications in which concerns about customer-specific performance standards and increasing respect for the safety of their environment by participants in watersports have come together in innovative composite designs.

5.7 Composite Materials-Based Sports and Equipment

Skis board, skiing, and snowboards are made up of composite materials that are directly linked to the safety and quality of life of the participants, and the construction of the skis and the material is more complicated. Wooden light and cheap, but it is out of shape to be easily affected by humidity. Ski fiber composites are ideal for any kind of ice, snow and easy maintenance.

5.7.1 Surfboard

The surfboard is a critical piece of equipment for surfing. Since the Hawaiians began surfing on wooden planks, the modern surfboard has come a long way in design and construction. The modern surfboard is light and solid, handmade from foam by professional shapers, and finished with a coat of fiberglass. But this isn't a static art; surfboard design's cutting-edge shifts as quickly as a cold surfer does on a windy day. Surprisingly, though it may seem, the material science of "fast" windsurfing boards is as sophisticated as racing boats. The board's base consists of an extruded foam polystyrene filler wrapped in fiberglass as shown in Fig. 5.1 [32]. Many spun graphite fiber strands embedded in a PVC resin matrix are wrapped around the heart. In turn, four layers of high-stiffness E-glass fiber weave enclose this PVC/fiber composition. Finally, the whole is contained within a composite of glass-fiber-reinforced epoxy, with Kevlar's extra fiber reinforcement in parts likely to be exposed to additional wear and tear. Obviously, only specialist companies can manufacture surfboards of this complexity. Some enthusiasts, however, like to build their panels. Kits can be purchased using extruded foam polystyrene (EPS) as a core product from which boards are made. This is then lined with resin-shaped glass fiber (or Kevlar fiber) weaving. More recently, a moldable polyethylene copolymer was used to make simplified surfboard constructions [6].

Fig. 5.1 Surfboards

5.7.2 Sailing Boat

A boat is, as we all know, a form of watercraft primarily designed to travel in near-shore areas or inland waterways such as rivers and lakes. Of course, what makes a boat different from a ship is its smaller size, and less ability to carry compared to the latter. However, a boat's definition—its size, shape, and capability—varies by purpose. Kevlar helps to make hulls lighter, stronger, and much less likely to break under pressure. Although a boat is described in the modern naval terms as a watercraft that is small enough to carry a ship abroad, some boats are measured up to 1,000 feet long. Likewise, several boats are intended to provide service, not in near-shore areas, but the offshore setting. Canada Spirit Open 60 yacht, as shown in Fig. 5.2 [33], took part in the 2008 Vendome round-the-world solo challenge [6].

Fig. 5.2 Sailing and boating

Fig. 5.3 Hiking shoes

5.7.3 Hiking Shoes

The difference between walking and hiking is grim. While both activities include walking on foot, many people classify themselves as merely walkers or hikers. Comparing the two events and opposing them helps to differentiate the two. Hiking boots are specially made footwear that protects the feet and ankles during outdoor walking activities such as hiking. They are one of the hiking gear's most valuable things, as their consistency and reliability can determine the ability of a hiker to travel long distances without injury. Manufacturers of hiking boots shown in Fig. 5.3 [34], use Kevlar for durability in uppers, soles and laces.

5.7.4 Snowboard/Ski Board

Manufacturers of snowboards like shown in Fig. 5.4, use Kevlar as a building material to help increase board stability, reduce chatter (vibration), and reduce weight. Kevlar helps decks keep their "pop" longer in skateboards and resist breakage. Kevlar is used for lightweight impact and abrasion resistance surfboards [6].

Kevlar helps make high-performance skis and ski boots smoother, stiffer, and more flexible and improves vibration damping. The qualities expected for high-performance skis are speed, stability, and good maneuverability. Kevlar tubing

Fig. 5.4 Snowboards

Fig. 5.5 Skis boards

allows ski poles as shown in Fig. 5.5, to be lighter, stronger, and more stable. Kevlar provide lightweight protection for racers for gloves used in slalom competitions [6].

5.7.5 Bicycle

The stick with carbon fiber tube and aluminum alloy joint was developed in the mid-1980s by Italy, France, Britain, and the United States. Its frame is chrome-molybdenum steel frame which is lightweight and strong, and its stiffness is higher than a normal steel frame. The well-known German rider, who won the Ulrich/mount men's cycling road race, is made of carbon fiber-reinforced composite material support, just 715 kg of weight. The products used for the bicycle as shown in Fig. 5.6 [35], frames are dominated for production roadsters by steel and steel alloys such as low or medium carbon steels or for competition cyc1es chromium-molybdenum-manganese steels. Certain components are made of copper, steel, titanium, and fiber/epoxy carbon composites.

The construction of the bicycle frame is a challenging environment for applying the new lightweight composite materials. Such new materials provide the frame with a lightweight structure with very high strength and durability, high rigidity, and excellent resistance to fatigue and corrosion. These include high rigidity (carbon fibers), better resilience (Kevlar fibers), and enough resistance to damping (ceramic fibers) [6].

Fig. 5.6 Bicycle made from high-performance fibers

5.7.6 Sports Racket

Today's world's big, middle-class tennis rackets are made mostly of carbon fiber composite materials. Several companies like the United States Chemold used carbon fibers in a tennis racket. Big tennis rackets as shown in Fig. 5.7 [36], can be made of carbon fiber composite materials, which has better shock-absorbing performance. Compared to other materials, carbon fiber used in tennis rackets has different advantages; creates a large tennis racket: wood compared to the past, under the same weight, the racket area can increase about 115 times, the cable tension rises by 20–45% on average.

Kevlar construction in tennis, racquetball, squash, and badminton racquets, as shown in Fig. 5.8 [37], prevent cracking and breakage. Kevlar strings do not stretch,

Fig. 5.7 Different types of rackets

Fig. 5.8 Tennis racket

and split less often than traditional strings. Kevlar is also used for vibration-damping purposes, and to protect against damage to the carbon fiber, the leading protection of ultra-rigid lightweight tennis rackets. Many tennis shoe models on the upper toe portion have used Kevlar to prevent the abrasion that occurs when players drag their toes during a serve.

5.7.7 Tennis/Squash Balls

Originally made of a solid rubber core, tennis balls are covered by a flannel stitch, as shown in Fig. 5.9 [38]. This was subsequently improved by hollowing the core

Fig. 5.9 Tennis ball

Fig. 5.10 Squash ball

and pressuring it with gas. Chemicals that generate gas inside the ball are added before the balls are sealed. To achieve a uniform thickness of the wall and a high degree of reproducibility, it is necessary to mold the separate twin half-shells. A synthetic nylon and wool composite now replaces the flannel cloth, and a vulcanized rubber seam replaces the cloth stitching used earlier. High-styrene resin, cellulosic fillers, aramid plastic resin, and (recently) unsaturated carboxylic acid copolymers (combinations of two or more polymers) are used in balls. The outer casing cloth has a high content of wool (50–60%), but nylon fibers make up the balance of the fiber content for optimum bounce properties.

Like tennis, squash players have four different ball styles to choose from, each varying in size, weight, and rebound properties. Besides these variations, a squash ball's dynamic behavior is also affected by the court wall's temperature and material. Therefore, an acceptable surface friction value is required to create the right rebound angle array. In particular, the high deformation of an impacted squash ball requires excellent durability for the joint between the ball's two half-shells. Squash balls, as shown in Fig. 5.10 [39], have traditionally been made of carbon-black impregnated rubber compounds that tended to mark the squash court's walls. Most balls, however, are now based on polymer materials. A squash ball's manufacturing process is not the same as a tennis ball; however, the exact specification of the material is a closely guarded secret.

5.7.8 Hockey

Many players in ice and field hockey opt for reinforced Kevlar sticks because they help them to be lightweight and keep their shape better than fiberglass or wood, as shown in Fig. 5.11 [40]. Kevlar helps to prevent a sharp break when a stick breaks, which can injure another player. Goalie masks use Kevlar for both ice hockey and field hockey, as it helps with resistance to light impact. Kevlar even helps to protect

Fig. 5.11 Hockey stick

spectators. It is woven into the big nets hanging between the ice rink walls and the fans sitting on the path of errant shots [6].

5.7.9 Motorbike Racing

A motorcycle is a two-or three-wheeled motor vehicle, also called a motorbike, cart, or cycle. Motorcycle design varies widely to suit a range of purposes: long-distance travel, commuting, cycling, a sport like racing, and off-road riding. Stiffness, impact tolerance and thermal abrasion tolerance have made Kevlar more popular with motorcycle component manufacturers and protective clothing manufacturers. Kevlar can be used in motorcycle tires, wheels, drive belts, composite parts, shoes, jackets, gloves, and helmets, as shown in Fig. 5.12 [41].

5.7.10 Baseball

Baseball bats shown in Fig. 5.13 [42] made with Kevlar have improved vibration damping, slower swing speed, and a more prominent "sweet spot" on the part of the bat where hitters prefer contact with the ball.

5.7.11 Canoes and Kayaks

Many canoeing types are known and used as sports include canoe sailing, canoe polo, playboating, intense surfing, whitewater slalom, and surf skiing. Some recreational

Fig. 5.12 Racing motorbike

Fig. 5.13 Baseball and baseball bat

uses include small-scale sailing, whitewater, sea kayaking, and canoeing. Hulls of Kevlar made canoes and kayaks, as shown in Fig. 5.14 [43], are easier to carry and navigate because they are lighter than those built from other materials, with better

Fig. 5.14 Canoes and kayaks

Fig. 5.15 Formula 1 racing Car

impact resistance. Besides, placing Kevlar in paddles helps to increase strength, durability, and resistance to impact.

5.7.12 Racing Cars

For NASCAR ® racecar bodies and air barriers, Kevlar fiber replaces fiberglass-reinforced plastic because it does not crack or leave debris on the ground after a collision, which can lead to improved protection and shorter delays. Kevlar® is used in the HANS system. This lifesaving reinforcing attachment protects the driver's head and neck, which helps to withstand impact forces that are powerful enough to destroy the vertebrae of the neck. For greater comfort and safety, helmets, suits, and gloves use a combination of Kevlar fibers and DuPont™ Nomex ® flame-resistant fibers. Formula 1 cars, as shown in Fig. 5.15 [44], use Kevlar belts to help retain wheels that fall off during collisions, stopping them from flying off the track and into the stands.

5.8 Conclusions

The advanced countries have been using their strengths in the field of materials and engineering technology in recent years. The application of composite materials in the field of sporting goods has rendered remarkable accomplishments unceasingly. For example tennis racket skeleton is made using carbon fiber, aramid fiber, or ceramic fiber-reinforced composites. Ski sticks are developed with laminated composite materials. Paddle, golf, and hockey sticks are also developed using advanced composite materials. In the area of sports equipment, fiber-reinforced composites have developed a larger market. The tougher standards are that the fiber-reinforced composite material added to the sporting goods, is the standard in the growth of the sporting goods industry in the twenty-first century. Kevlar has become a popular choice for both equipment manufacturers and customers in the search for lighter, and stronger, sporting goods. Even appealing to athletes, outdoor enthusiasts and anyone else looking for better performance in sports goods.

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Chapter 6
Textile Fibers for Automobiles

Faheem Ahmad

Abstract The role of the textile fibers in various components of automobiles has evolved in order to meet the demand of high fuel economy without compromising the durability. The conventional natural and synthetic fibers, along with high-performance fibers, are used to develop woven, knitted, nonwoven, and composite structures for different components of the automobiles. This chapter describes the applications of textile fibers in different automobiles. Moreover, some advantages and limitations of these fibers are also highlighted. The composites made from natural fibers are frequently used for interior of the vehicles such as car seats, door panels, and door liners. The natural fibers are eco-friendly and have better comfort properties, but their low mechanical strength and low resistance to UV light are the major drawbacks. The synthetic fibers are also used in automobiles which have good mechanical properties, high abrasion resistance, and sound insulation.

Textiles are the necessary part of human life which used to protect and provide comfort to humans. The functions of protection and comfort are achieved and classified in the forms of clothings and technical textiles [1–3]. The technical textiles are applied to perform certain functions rather than aesthetic such as construction buildings, agriculture, medical, packaging, sports, and automobiles [4]. The automobile textiles are one of the most distinctive and flourishing class of technical textiles which deals with cars, buses, trains, aircrafts, and other vehicles. The different components of automobiles are produced from various textile assemblies like fibers, filaments, fabrics, and composites. These assemblies are employed into different vehicles for passenger seats, safety belts, thermal insulation, acoustic, filters, hoodliner, and carpets. The automotive components which are made from textile materials are described in Table 6.1 [4, 5]. The weight of these components is around 20 kg in a single car which are mostly used in the interior of cars. The properties and application of these automotive components are mainly depending upon the fibers used to constitute these components The physical and mechanical

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Table 6.1 Automotive components made from textiles

Vehicle component	Textile assemblies
Airbags	Fabrics for automotive airbags
Seat covers	Woven and knitted seat covers and backing fabrics
Seat belts	Narrow woven safety belt fabric
Tire cords	Fabric reinforcement for vehicle tires
Drive belts	Fabric reinforcement for automotive drive belts
Automobile carpets for interior	Tufted or needle punched fabrics
Trim	Woven, knitted and nonwoven fabrics based trims for boot liners, headliners, parcel shelves, and door panels
Filters	Filtration media for engine, air intake, fuel filtration
Hose	Fabric reinforcement for automotive hoses

properties of these automotive components, mainly depend upon the type of fibers used to produce these component [[6]. Textile fibers are the building blocks of any textile assembly. Therefore, the choice of textile fibers is very important in order to achieve desired properties from any conventional or technical textiles like automotive textiles. Both natural and synthetic fibers are used in pure and blend form to produce automotive textiles [7, 8]. In this chapter, we present the utilization of various natural and synthetic textile fibers in automobile industry.

6.1 Natural Fibers

Textile fibers are the fundamental units of any textile product which are defined as materials that have flexibility and have high length to width ratio. Natural fibers are the materials which have source from plants, animals and minerals. The most commonly used natural fibers are flax, sisal, hemp, cotton, wool, silk and jute which exist in fibrous or filament forms. These fibers are easily convertible to yarns for fabrics or structured directly into fabrics which are called nonwovens. The structural property relationship of these fibers is key to develop any textile product which mainly depends upon the chemical composition of these fibers. The major component of the plant-based fibers is cellulose, which is an organic material that contains thousands of glucose units. The lignocellulosic polymer is also obtained from the cellulosic source like stalk, husk, bast, fruits and grass. The animal fibers like wool and silk constitute from keratin and fibroin [9–11].

6.1.1 Applications

The first natural fiber used for technical textiles was plant straws which combined with clay for construction building about 3000 years ago in Egypt. The use of hemp fiber in China was also reported by the archaeological department. The first four-wheeled vehicle was developed in 2600 BC which was built with wood and leather. The current automotive industry is expanding rapidly, which is expected to reach 2 billion vehicles by 2030. One of the major demands inside the structure of modern vehicles is the fuel economy, whereas the aesthetics and comfort of the interior of the vehicles are also essential. The natural fibers have good mechanical and comfort properties to meet the demands of modern vehicles. Additionally, the new regulations for automobile industry encourage the use of eco-friendly materials which are recyclable and cut down carbon oxide emissions. The automobile industry adds around 25% of the total greenhouse gas emissions in industrialized countries. Therefore, the textile fibers from natural sources are good choice for the automotive industry to improve the fuel efficiency and fulfill the aesthetic appeal. These fibers are mostly used in the interior of the different vehicle components like seat covers, seat belts, door panels, dashboards, back cushions and boot lining [12, 13]. The various components of a car made from textile materials are shown in Fig. 6.1.

The natural fibers are usually structured into the composites with various resins to impart into the interior of automobiles. The natural fibers are usually structured into textiles composites by using different resins and these composites are used in the interior of automobiles. The natural fibers reinforced composites also flexible with good tensile strength and these have the ease of converting into complex vehicle

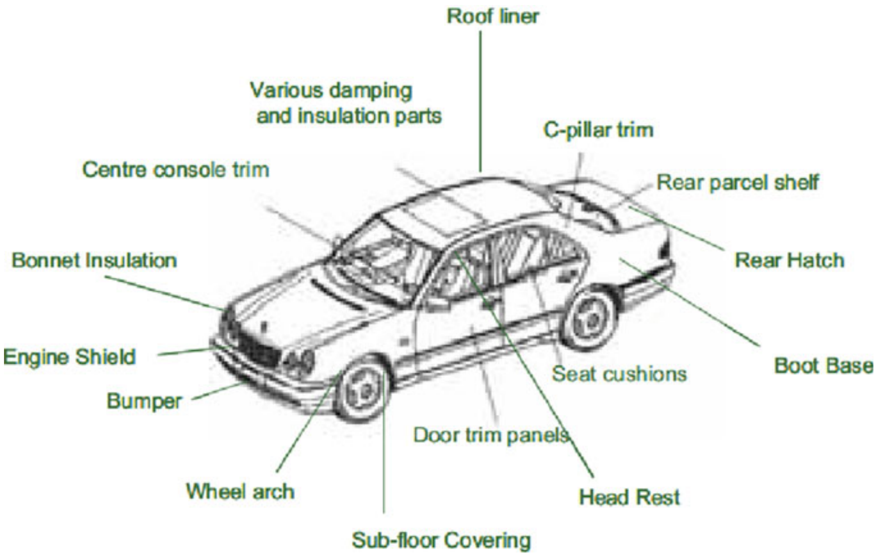

Fig. 6.1 Components of a car made from textile materials

Table 6.2 Natural Fibers based vehicle components

Company	Model	Vehicle components
Honda	Pilot	Cargo compartment
Toyota	Brevis, Raum, Harrier	Seat covers, mats, door panels
BMW	3, 5, 7 series	Acoustic panel, seat covers, door panels, headliner panel
Ford	Mondeo CD 162, Freastar	Door panels, boot liner,
Volkswagen	GolfA4, Bora, Passat, Variant,	Door panels, boot liner, seat covers,
Audi	A2, A3, A4, A6, A8	Seat backs, door panels, boot liner
Rover	2000	Thermal insulation, storage area
Volvo	C70, V70	Seating pad, cargo floor
Diamler AG	A, C, E, S series	Door panels, pillar covers, dashboard
Lotus	ECO Elise	Seats, carpets, body panels
Mitsubishi	Space star, Colt	Door panels, cargo compartment floor,
Fiat	Punto, Brava, Marea,	Door panel
Renault	Clio, Twingo Rear	Parcel shelf
Opel	Astra, Vectra, Zafira	Door panels, headliner panel,
Saturn	L3000	Door panels

interior shapes. Therefore, the automotive textile industry is one of the largest user of natural fibers reinforced composites. The utilization of natural fibers in various components of automobiles is summarized in Table 6.2. The cotton and jute nonwovens fibrous composites are considered to be highly efficient for sound absorption in modern automobile industry. Moreover, coir fiber is also reported as good acoustic material for the vehicles.

The natural fibers such as jute, hemp, sisal and coir are also used as interior fillers in various automobiles which reduce the cost of the vehicle. The door panels of different cars are prepared by natural fibers which reduced the weight of the car door. A car manufactured by Mercedes has used fibers made from wood pulp in car doors which reduced the weight around 20%. The car seats are the most important component of any vehicle which demands strength, comfort and aesthetic. The car seats are also produced by natural fibers like wool for commercial purpose. [14–16].

6.1.2 Advantages and Drawbacks

The use of natural fibers in automobile industry carries a lot of advantages such as biocompatibility, biodegradability and nontoxicity. Moreover, the vehicle components made from natural fibers are lightweight, which contributes to the fuel economy of vehicles. The natural fibers are low-cost material and are easy to assemble into complex structures of the vehicle's interior.

As most of the natural fibers used in automotive textiles are cellulose-based materials so their ability to absorb high moisture is a disadvantage for the vehicle components. The presence of moisture in the fibrous structure decreases their strength and their degradation period is shortened. The moisture swells the fibers which results in the change of the shape and dimension of the automotive components. Therefore, few chemical treatments need to be applied to these fibers to improve their mechanical properties which ultimately increase the cost of the material [13, 17, 18].

6.2 Synthetic Fibers

The safety and comfort of automobiles are the basic requirements for users of any kind of a vehicle. These two parameters become more important for the selection of material to be used in the interior of the vehicles. The synthetic fibers like polyester, polyamide, acrylic, and polypropylene are considered to the right selection to fulfill the requirements of safety and comfort of any automobile. These synthetic fibers have the advantages of high mechanical strength, thermal resistance, dimensional stability, abrasion resistance, moisture resistance, and UV resistance over natural fibers. The most used synthetic fiber is polyester which has a big share of 42% in automobile industry while 26% of polyamide 6.6 is used. These fibers are also low cost and very easy to shape into any structure of automotive component [18, 19].

6.2.1 Applications

The seats of a car or other passenger vehicles are the most attractive part of the interior, which demand durability and aesthetics in their shapes and structures. A fabric of 5 to 6 m^2 is usually used in the car upholstery and seats. The car seats made from textile fabric are shown in Fig. 6.2. The car seats are mostly prepared by polyester fiber which is fabricated by weaving or circular and warp knitting. The vehicle's seats are also manufactured from acrylic, PVC, and viscose fibers. The acrylic fiber-based car seats have the advantage of very high resistance to UV light which is a critical parameter as the vehicles have longer exposure to the sunlight. [20, 21].

The carpets (Fig. 6.3) inside the interior of the cars are usually prepared by polyester and polypropylene as these materials have good soil and abrasion resistance. The polyester and polypropylene needle punched nonwoven or felts are used for carpets which also have good acoustic properties. The sound insulation is a key requirement for vehicles. Therefore, those textile fibers are selected for the interior of the automobile, which provide good sound insulation.. The polyester-based nonwovens are reported as good sound insulation materials and their blend with hollow polyester improved their sound insulation properties. Therefore, PET nonwovens are

Fig. 6.2 Car seats prepared from textile fabric

Fig. 6.3 Carpet for car interior made from textile fabric

used in door panels, headliners, boot liners, and parcel shelves as sound absorbers [22, 23].

The carpet for the interior of the automobile made from recycled polyester was reported in literature. The recycled PET fibers were obtained from PET bottles and needle punched nonwoven carpet was produced for automotive. The recycled PET nonwoven fabric showed a good abrasion resistance which was comparable with virgin PET nonwoven fabric [24].

The door panels of cars are important components of the interior of the vehicles which are usually divided into two parts. The fabric at the lower part of the panel is connected with floor fabric while the upper part contains upholstery fabric. The door panel fabric is commonly produced from PET nonwoven which has better mechanical properties. Additionally, the PET fibers are also dyed with appropriate chemicals to minimize the effect of UV light on door panels. The polypropylene fiber-based fabrics are also employed in these door panels which have superior abrasion resistance than dyed PET fabrics [19, 22].

The boot liners or cargo liners are the assemblies inside the boot space to protect the cargo or luggage from mechanical stress and dust in the vehicles. These boot liners are usually manufactured from polypropylene or PET-based fabrics. The major requirements for boot liners are flexibility, dimensional stability, and moisture resistance so the PET is preferred over PP as PET has higher mechanical strength [22].

The roof headliners are most used textiles automotive components of the interior of the vehicles. These contribute about 13% of the textile materials used for automobiles. The fabric for headliner (Fig. 6.4) is manufactured by using polyester needle punched nonwoven. The PET nonwoven fabric has good abrasion resistance, good sound absorption, and smooth appearance. Moreover, this PET fabric is coated with various chemicals like phenolic resins and the face of the fabric is covered with polyurethane foam [25].

The tires are the essential part of any vehicle which play a vital role in safety and economy. A tire contains various components like sidewall, tread, ply, apex, bundle,

Fig. 6.4 Textile fabric-based headliner

and inner liner. The automotive tires are mostly prepared by steel and rubber. The synthetic textile fibers like polyacrylate, nylon, polyester, rayon, and Kevlar are also structured into ply cords of the tires. The major requirements for tires ply cords are high tensile strength, flexibility, heat resistance, and abrasion resistance [22, 26, 27].

The air filters and fuel filters are also important segments of the automobiles. An air filter provides the dust free air inside the vehicle while fuel filter protects the engine from various contaminations present inside the fuel. The textile fibers like polyester, polyacrylate, which are converted into laminates and nonwovens structures which have the excellent ability to hinder dirt and dust particles.

The fuel filters are prepared from polyacrylate fibers which are imparted between fuel tank and engine. These filters are used to remove dirt and other contamination from fuel. The PET fibers based filters are also used, but these filters have lower impact resistance as compared to polyacrylate fuel filters. The multilayer polyacrylate fibers based fuel filters are also manufactured, in which the fibers are embedded between plastic layers [28–30].

Airbags are the gas pillows which contribute about 3.7% of the textiles used for automotive textiles. The airbags used for safety purpose are shown in Fig. 6.5. These airbags are the safety components inside the vehicles which protect the passengers in the event of any collision. The airbags are placed for driver, front passengers, and back passengers. The airbags are prepared by using nylon 6.6. They are usually treated with silicone to improve the impact resistance.

The knitted and nonwoven nylon 6.6 fabrics are designed for the safety airbags. The major requirements for airbag's fabric are tensile strength, good impact resistance, and high tear strength. The fabrics for airbags also need to have good packability and coating adhesion [31, 32].

The safety belts are another important component assembled inside the vehicles to ensure the safety of drivers and passengers during the event of any dangerous collision. These belts are manufactured from nylon, polyester, or polyacrylate fibers. The fabric used for seat belts is manufactured from nylon or polyester fibers. It has

Fig. 6.5 Airbags of nylon 6.6

high tensile strength, good elongation, UV resistant, and high abrasion resistance which are the important requirements for seat belts.

The helmet is a safety component which is used by the motorbikers. The helmets are usually prepared from synthetic materials like polypropylene foam or polystyrene foam imparted inside the outer layers of glass or acrylonitrile butadiene styrene fibers [19, 25].

6.2.2 Advantages and Drawbacks

The biggest advantages of synthetic fibers are their availability and cost effectiveness. The synthetic fibers also have excellent properties like abrasion resistance, chemical resistance, and have good thermal resistance and sound insulation. Moreover, these fibers also have the ability to form blends and easy to shape into various composites. These are also low-density materials like polypropylene which reduce the weight of the automotive components. The automotive components made from polyester and acrylic have high UV resistance. The low moisture absorbency of synthetic fibers is their major drawback. Moreover, fibers like polyamide 6 and 6.6 consume huge amount of energy during their manufacturing.

6.3 High-Performance Fibers

High-performance fibers are the materials which are manufactured for functional applications, so these fibers have ultra-high tensile strength, high modulus, high impact strength, good thermal, and chemical resistance. Therefore, the high-performance fibers like carbon, glass, Kevlar are used in the automobile industry in various components of vehicles. These high-performance fibers in the multifilament roving form are used which are usually twisted or untwisted. The improvement in fuel efficiency of automobiles is a big challenge for the manufacturers. So the availability of carbon and glass fibers provided a good alternative for the automotive industry to replace steel and aluminum.

These high-performance fibers are lightweight and give better mechanical properties than steel and aluminum. The use of high-performance fibers can reduce the weight of automobiles from 50 to 80%. It was reported that the fuel economy of the automobile improves by 7% for every 10%, approximately weight reduction from a vehicle's total weight. Therefore, the use of high-performance fibers has grown rapidly in recent years in the automotive industry. These fibers are used in their composite form for sports cars, air crafts, and boats. The Airbus A380 and Boeing 787 Dreamliner have manufactured by using carbon-based composites in the aircraft structures which reduced the overall weight and ultimately cut down the utilization of fuel which is also a useful contribution to reduce the air pollution.

The glass fiber-based polymer composites are also used in automobile industry. These composites are employed to prepare the vehicle's outer body panels, air ducts, bumper beam, and engine parts which are lighter than conventional materials. The glass fibers based clutches and brake pads of cars are also manufactured as glass fiber has good abrasion resistance. The glass fiber reinforced composites are also applied to prepare wings of air crafts.

The manufacturing of glass/carbon fibers based composite for the car bumper beam was reported. The composite was 33% lighter and had good impact strength as compared to the conventional bumper beams.

Though the high-performance fibers have several advantages but their availability and high price are big issues for the automotive industry. Therefore, the attempt has been made to replace them with natural fibers like curana, sisal, and hemp [19, 22, 25, 33]

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Chapter 7
Fibers for Geotextiles

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Abstract Nowadays, the application of technical textiles is increasing significantly in different segments of life. Geotextile is the category of technical textiles that has emerged as a promising field both in developing and underdeveloped countries in the recent past. This is because of the fact that Geotextile has vast and diversified applications in mega civil projects. In this scenario, diversified utilization of different fibers has also been observed for the manufacturing of geotextile such that it can withstand the intended end-use. Earlier, the synthetic fibers were used in most of the geotextiles with little application of natural fibers. However, the extensive increase in the use of natural fibers is observed in recent times, particularly in developing countries. This chapter has classified the fibers into three categories: natural fibers, synthetic fibers, and high-performance fibers. In each category, the fibers for the geotextiles have been described comprehensively with respect to their applications, advantages, and disadvantages.

7.1 Introduction

Because of rapid development in the field of science and technology the researchers and scientists are trying to explore novel dimensions in the field of textile. These continued efforts generated the idea of technical textiles. As the name indicates, these are special materials which are manufactured primarily for their performance and high-end applications. Technical textiles are broadly classified in twelve different

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categories like Agrotech, Sportech, Buildtech, Medtech, etc. [1]. Out of these classes, Geotextiles has emerged as a promising domain because of its vast and diversified applications like its popular usage in mega civil projects (dams, roads, bridges, etc.), special design structures for high strength and flexible structures in earthquake zones as well as for fire retardant constructions. ASTM D4439 defines geotextiles as [2]:

> A permeable geosynthetic comprised solely of textiles. Geotextiles perform several functions in geotechnical engineering applications including separation, filtration; drainage; reinforcement; and protection.

Textile materials find their application in geotextiles in the form of fibers, yarns, and fabrics (woven, knitted, and nonwoven). However woven fabrics are used to impart better support, strength, and stabilization. On the other hand, nonwoven textile materials have shorter life cycle but they are less costly [1].

The concept of geotextiles is not new for human beings. Since from ancient times human beings are using straw, brushwood, and skins as reinforcement materials. However, it was not possible to achieve desired properties with the primary techniques and materials. Then human beings started using different natural materials however the revolution in this field came with the introduction of synthetic materials during the twentieth century which opened new domains of geotextiles with improved properties and desired characteristics. The idea of geotextile was first introduced back in 1950s when it was used for filtration. After that it has been applied in a wide range of applications that includes drainage, separation, reinforcement, and stabilization. Global awareness regarding superior advantages of geotextiles over traditional products in terms of high load-bearing ability, flexibility, high strength, and permeability is increasing day by day. Thus, geotextiles have been considered as the emerging field of technical textiles even in the developing countries nowadays.

Based on the textile structure being used, the technical textiles can be categorized into the nonwoven, composite, and others (woven, knitted, etc.). However, geotextiles are divided into three types that include nonwoven, woven, and knitted. In geotextiles, 65% of the products are made from nonwoven fabrics which are further utilized in filtration and civil engineering. Heat-bonded nonwoven and needle punched nonwoven are mainly used for geotextiles. Heat-bonded nonwovens are made from continuous filaments while needle punched nonwoven is made from both continuous filaments and staple filaments. Resin-bonded nonwovens are also used in geotextiles but their application is very rare [3]. Mechanical coherence is attained by fiber entanglement and heat so that the product can perform well as nonwoven geotextiles.

After nonwoven, 25% of geotextile products are manufactured using woven fabrics. Heavyweight geotextiles are used for stabilization and reinforcement of the soil while lightweight geotextiles are used for filtration, erosion control, and soil separation. In this regard plain weave fabric is considered best because of its good tensile strength, tensile modulus, and elongation at break. Woven geotextiles may consist of monofilaments and multifilament fibers while combinations of woven and nonwovens are also used in geotextiles [3]. On the other hand, the application of knitted geotextiles is very less as compared to woven and nonwoven. Knitted structure for technical fabrics may consist of mono-axial, bi-axial, and multiaxial structures. Knitted fabric is considered more stable in multiaxial structure as compared to the mono axial. Such knitted fabrics are used in geotextiles for road construction, railway construction, slope, and bank reinforcement. Knitted geotextiles have exceptional tear strength as compared to woven geotextiles. Knitted geotextiles are lighter, easy to handle and lay on the site, and requires less transport and labor cost.

Filtration is considered as a pioneer application of geotextile, however with the increased use of natural and synthetic fibers, geotextiles are now used in a wide range of applications. These applications include drainage, reinforcement, separation, embankment, erosion control, etc. Key applications of geotextiles include riverbank protection, seabed protection, geo bags, concrete mattress, lakes and reservoirs, coastal protection, water flow applications, vertical screens, land reclamation, embankments, railways, landfills, earth reinforcing, reflective cracking, anchoring, and slit fences. Table 7.1 provides a comparison of primary, secondary, and tertiary functions of geotextiles in various application areas [4].

Keeping in view the above-mentioned applications, geotextile products must have some characteristics to withstand the requirements of the end use. For this purpose, three main properties that include mechanical properties, filtration ability, and chemical resistance of geotextiles are mainly considered. Good mechanical properties ensure that the product can withstand high stress and resist the damage over a specific period of time. The filtration ability of geotextiles means the liquid passes through the interface of soil and permeable textile such that the integrity of the interface is maintained. However, the chemical resistance in geotextiles is required only in extreme chemical environment like sites for waste disposal, polluted industrial areas, and chemical effluent containers. The chemical resistant geotextile ensures to pass the toxic effluent such that the soil and textile material remain stable. The attainment of

Table 7.1 Comparisons of geotextile functions with respect to their applications

Application	Geotextile function			
	Reinforcement	Separation	Filtration	Drainage
Roads	P	T	T	S
Railroads	S	P	S	P
Drainage	T	S	S	P
Steep slopes	P	T	T	S
Landfills	S	P	P	S
Walls	P	T	T	T
Soil reinforcement	P	T	S	S
Land reclamation	S	S	P	S
Marine causeways	S	T	S	P
River protection	S	T	P	S

P = Primary function; S = Secondary function; T = Tertiary function all these characteristics depends a lot on the material being selected for the geotextiles. Thus, raw material for the manufacturing of geotextiles should be selected to develop such working effect that can meet the requirements of ultimate applications.

In this regard, a wide range of fibers is available that can be used to manufacture the geotextiles. These fibers are classified as natural fibers, synthetic fibers, and high performance fibers. All these classes are briefly explained with respect to their applications, advantages, and disadvantages in the manufacturing of geotextiles.

7.2 Natural Fibers

In developed countries, the industry of synthetic geotextile is well established however, the geotextiles made from natural fibers are also gaining attention. The first reason for this gain is the temporary application of geotextiles for a shorter period of time such as temporary haul roads, basal reinforcements, etc. Secondly, the synthetic geotextiles are expensive that is why rarely used in developing countries. In such scenarios, natural fibers-based geotextiles become an alternate choice that is cheap and easily available in most of the developing and underdeveloped country. Lastly, the dependence on renewable resources has been increased due to awareness about the scarring effects of nonrenewable resources. This century would be cellulose century because several renewable plant resources have been discovered. The natural fibers are generally stated as renewable and sustainable [5].

Natural fibers are broadly divided into vegetable fibers, animal fibers, and mineral fibers but most of them do not have the essential properties with respect to the requirements of geotextiles. From all these, vegetable fibers consist of cellulose as a major constituent and have high capability for use in geotextile because vegetable fibers have higher strength, water absorption properties, and low elongation. While animal fibers mostly consist of protein, e.g., silk and wool that have low strength compared to vegetable fibers. Moreover, the major constitution of mineral fibers is silica (SiO2) or other metals. These fibers have the capability to resist heat and are non-flammable, but have high cost, high brittleness, low strength, and low flexibility [5–9].

Natural materials such as wood, reeds, bamboo, coconut, and skins have been used for construction of buildings for thousands of years in addition being used as fuel for cooking and to keep the environment warm. The use of natural fibers in construction and buildings has been discussed in various literatures and books. The literature tells that the natural fibers have been used since early 4000 BC in Europe, 3000 BC in Egypt, and 6000 BC in China. The fabrics made from natural fibers such as cotton and jute, have been used for strengthening the road pavements in 1920s and 1930s in Scotland and USA [10]. In the 1930s, woven fabric made from jute was being used as subgrade support for the settlement of the soil before construction of a highway road in Aberdeen [11]. The fabrics made from jute and cotton fibers have been experimented in India as geotextile for construction of roads to increase the structural durability. In 1930s Jute fabric was used in Germany and India to decrease the cracking and porous effects in road structure.

All-natural fibers are biodegradable, renewable, and non-toxic. Moreover, these fibers do not cause the pollution of the environment and decompose during the biological cycles of soil penetrability. Thus, these fibers are sustainable and eco-friendly. The decomposing of natural fibers in the soil helps in retention of moisture. They easily mix with soil and enhance soil permeability, organic contents in soil, fertility, and texture. Moreover, they increase the growth of vegetable plants by forming a microclimate around the soil. In various ground engineering situations such as temporary haul roads for heavy vehicles for transportation of bulk materials and consolidation drains, geotextiles are only used to function for a constrained lifetime, while appropriate synthetic materials/fibers have a long lifetime. All-natural geotextiles are environmentally friendly and biodegradable and have a short feasible life that is enough to increase soil behavior.

The applications of natural fibers as geotextiles mainly depend on the location of the site and the fabric properties as well as manufacturing process of the fabric. The geotextile work as a separator when it is placed between the two materials, i.e., between soil and aggregates, which have the capability to mix with each other when they are pressed together under the action of recycling load. So, the geotextile materials prevent the mixing of the two or more different materials and retain the properties of materials. The tensile strength of the soil increases comparatively to plain soil when geotextiles are reinforced with soil. A geotextile acts as a tension membrane when it is kept between two different materials (i.e., aggregates and soil) having different pressure on both sides and balance the tension between two materials. The geotextiles are also used for the separation and filtration, slope safety, sealing, drainage, and erosion control purposes [12].

There are six major kinds of natural fibers that include: bast fibers (jute, flax, hemp, ramie, and kenaf), leaf fibers (abaca, sisal, and pineapple), seed fibers (coir, cotton, and kapok), core fibers (kenaf, hemp, and jute), grass and reed fibers (wheat, corn, and rice), and all other types (wood and roots) [5]. Among these natural fibers, Jute, Flax, Coir, Sisal, and Hemp fibers are being used in geotextile.

7.2.1 Jute Fibers

The Jute fiber is obtained from the stem and outer skin of Jute plants. These plant fibers are soft and flexible. They have a brownish color and can be easily bleached and dyed with different colors. India is the largest producer of Jute and the other countries are Bangladesh, Thailand, and China [11]. The Jute fibers have definite tenacity, absorbency, and transmissibility capacity. The Jute fibers as geotextile are being used for the construction of roads and pavements. According to one study by adopting suitable planning for the soil saving, almost 100 million km^2 Jute geotextile can be used each year. The physical condition of soil determines the type of Jute fabric used for geotextiles. Jute geotextiles are most effective where roads and ways are made over weak subgrade soils. Jute geotextiles are being used in various applications of civil engineering [13].

Applications
The lifetime of the roads and pavements constructed on soft soil can be increased by using Jute geotextile. The fabric made of Jute as separator resists the penetration of subgrade materials into the cavities of granular base course. Due to having permeability characteristics, the jute fabric also helps in faster dissipation of pore pressure and make sure the better drainage and increase the performance of road and pavements for prolonged time. The fabric of Jute is applied on pavements and roads over bridges for drainage and filtration purposes [14].

The Jute geotextile is also used to improve the performance of embankments. A Jute geotextile as woven fabric is used as a separator and reinforcement in embankment over soft subsoil and reduce the risk of flood. The reinforcement of Jute fabric reduces the erosion of soil and earth's surface during the rainy days, floods, and fast winds [12]. The Jute are also installed on the hill slopes to stop the continual movement of debris and landslides. Moreover, they are used for the formation of temporary passages to discharge the water during rainy days [15].

Advantages and Disadvantages

This is a multipurpose plant fiber that is biodegradable and eco-friendly. It has the capability to mix with the soil after decomposing and act as nutrients for plants. But fast biodegradability of jute fibers causes weakness of their use in geotextile. Yet its life duration can be extended for several years by different chemical and mechanical treatments [12].

7.2.2 Coir Fiber

It is also known as Coconut fiber that is extracted from the outer shell of the coconut. It has brownish color and strong in nature. India, Indonesia, and Sri Lanka are the leading producer of coir fiber with the contribution of 22%, 20%, and 9%, respectively. The coconut plant is famous as plant of life due to its application in all most every aspect of life [1]. Coir fibers are used in geotextiles and other home textiles such as floor mats and door mats, etc. Resistance to biodegradation of coir fibers is highest among other fibers due to the presence of high content of lignin. That is why the demand for the coir in geotextile is increasing day by day.

Applications
The most common applications of coir fibers in geotextiles are for the construction of roads and pavements. A coir geotextile as woven fabric is used as a separator and reinforcement in embankment over soft soil and reduce the risk of failure of roads and bridges. The fabric developed from coir fiber is used in filtration and drainage

on roads. Coir fibers are better options for geotextile due to their low cost compared to geosynthetic materials.

The coir woven fabric is reinforced in overlays or interlays and protects the land surface from runoff. It is being used for the stabilization of shoreline and for the formation of stormwater passage. The other applications of the Coir fibers include reinforcement of unpaved roads and mud walls, as sub-base layer in road pavements and soil stabilization during rainy seasons [16].

Advantages and Disadvantages

The surface of the coir geotextiles may contain wax, oil, pectin, and different types of impurities that have negative impact on the interaction of coir geotextile and soil. This effect can be minimized by the chemical treatment of coir geotextile [17]. It is observed that the adhesion properties of the treated coir geotextile with soil are much better than the untreated coir geotextile.

7.2.3 Hemp Fiber

Hemp is considered as one of the strongest members in a plant's family of bast fiber. It is mostly used in Asian countries. Hemp fiber is the one of the fastest-growing vegetable plants. It is available in different natural colors, i.e., cream brown and gray and cost-effective. Naturally this fiber has been gifted with high stiffness and tensile strength. Moreover, it has high sensitivity for moisture absorption, air permeability, and temperature resistance that enables Hemp fiber to use in multiple fields [18, 19].

Applications

Due to the high tensile strength and moisture absorption properties, Hemp fabric is used in riverbanks as reinforcement and protect the riverbanks from erosion [20]. Hemp is reinforced in soil to reduce the effect of mulching. It is also used as a separator and for drainage during the road construction.

Advantages and Disadvantages

Hemp fibers are eco-friendly and non-toxic. They can form mixed with the soil after decomposing and act as nutrients for plants, but they have very low "antimicrobial resistance" due to which they have a high degradation rate. Thus, to overcome this problem, hemp fibers are treated with different chemical solutions to increase their resistance against the microorganisms' attack.

7.2.4 Sisal Fiber

The sisal fiber is hard in nature and obtained from the leaves of the sisal vegetable plant. It is grown in hot and dry locations. It has creamy white or yellowish color.

Sisal grows in eco-friendly environment because there is no need of pesticides or any fertilizers for its farming. It has coarser surface and durable fiber as well as excellent ability to stretch. Sisal fiber is widely used in geotextile because it has the ability to resist bacterial attack, good stretch ability, and higher strength. Due to these characteristics Sisal fibers are widely used in civil engineering.

Application
The lifetime of the road constructed on soft soil can be increased using Sisal as geotextile. The Sisal fabric resists the penetration of fine soil into the cavities of the aggregates during the construction of roads when Sisal fabric is placed in between them. The woven fabric of Sisal fiber is enforced in soil to reduce the effect of erosion. Sisal fabric is used for the mulching process in which fabric is spread over the soil to retain moisture contents in it. Moreover, tension membrane made of Sisal fabric is kept between two different materials (i.e., aggregates and soil) having different pressure on both sides to balance the tension on both sides. It is also used as separator under roads where gravel particles have the possibility of penetration into the underlying clay due to the massive flow of traffic [21].

Advantages and Disadvantages
Sisal fibers are eco-friendly, biodegradable, and durable. It has the ability to control humidity as well anti-static in nature. Moreover, the Sisal fibers after decomposing in the soil help in improving its fertility. But the Sisal fiber cannot dye with artificial colors and it is difficult to use it in such areas where the humidity factor is high because Sisal is so absorbent.

7.2.5 Flax Fiber

Flax fiber is considered in the category of bast fiber and it is obtained from the flax plants. Flax plant is famous due to two reasons: one is linseed oil and the second is flax fiber. It is being used for manufacturing of cloth that is known as linen fabric. Flax fibers are soft, shiny, and flexible. It has usually gray color. It is typically used in nonwoven form when it is being used in geotextile [22].

Applications
The Flax fabric is reinforced in the soil to minimize the erosion effect in the land. Flax fabric is spread over soil to maintain the moisture level in soil. It also reduces the chances of failure of unpaved paths. Moreover, flax as geotextile is used for the separation, drainage, and reinforcement near the riverbanks [15].

Advantages and Disadvantages
Flax fibers are low cost, renewable, and eco-friendly. They have moisture absorption properties and durability. They have the ability like Hemp to form mixed with the soil

after decomposing and act as nutrients for plants, but they have very low "antimicrobial activity" due to which they have a high degradation rate. So, to overcome this problem, Flax fibers have treated with different chemical solutions to increase their resistance against the bacterial [20].

7.2.6 Comparison of Natural Fibers for Geotextiles

The general characteristics of natural fibers (Cellulose fibers) are different compared to synthetic or man-made cellulose fibers. The natural fibers have high tensile strength, moisture absorption ability, low elongation, and elastic while man-made cellulose fibers possess low strength, low modulus, high elongation and moisture absorption and poor elastic properties. Natural cellulose fibers have great ability to be used in geotextile due to these properties. A summary of the chemical, morphological, physical, and mechanical properties of natural fibers being used in geotextiles is given in Table 7.2.

The foremost aspect of using natural fibers in geotextile is that they have high tensile strength [1]. Natural fibers mostly consist of cellulose, hemicellulose, and lignin. The cellulose and hemi-cellulose portions provide the high mechanical

Table 7.2 Chemical composition, morphological, and physical properties of vegetable/plant fibers

1. *Chemical composition*					
Fiber types	Jute	Flax	Coir	Sisal	Hemp
Cellulose (%)	64.5	64	35–45	62	67
HemiCellulose (%)	12	16.5	1.25–2.5	12	16
Lignin (%)	11.8	2	30–46	10	3.5
Fat and wax (%)	0.5	1.5	1.3–1.8	0.3	1
Moisture contents (%)	10	10	20	10	10
2. *Morphological properties*					
Long length(cm)	150–360	20–140	15–35	60–100	100–300
Diameter (cm)	0.003–0.014	0.004–0.062	0.01–0.045	0.01–0.046	0.016
Cell length (cm)	0.08–0.6	0.44–7.7	0.03–0.1	0.08-0.8	0.5–5.5
Cell diameter (cm)	5–25	5–76	1.5–2.4	7–47	10–51
3. *Physical/mechanical properties*					
Specific gravity (%)	1.5	1.54	1.15–1.33	1.2–1.45	1.48
Specific heat (calg-1 °C-1)	0.324			0.317	0.323
density (g/cm^3)	1.46	14	1.25	1.33	1.5
Moisture absorption (%)	10–12	7	10	11	8
Modulus (GPa)	10–30	60–80	6	38	70
Tensile strength (MPa)	400–800	800–1500	220	600–700	550–900

strength and modulus while lignin contents in the fibers provide the barrier against the external heat. Moreover, natural fibers have pores in their structure that have air which is a good insulator against heat (0.026 W/mK at 25 °C) [23–29]. It can be seen from Table 7.2 that the tensile strength of natural fibers is increasing as the contents of cellulose and semi-cellulose are increasing. Moreover, the natural fibers have good moisture absorption ability due to their hydrophilic behavior but their mechanical strength change with quantity of moisture contents [30]. Therefore, the woven or nonwoven natural fabrics are reinforced in soil having high moisture contents before the construction of dams and roads near the riverbanks, etc.

7.3 Synthetic Fibers

The use of synthetic fibers in geotextiles is not a new phenomenon, however because of higher strength, non-biodegradable nature, and special purpose applications are responsible for the rise of synthetic fibers in geotextiles. The four main synthetic polymer fibers used in geotextiles are polyolefins (polyethylene and polypropylene), polyester and Polyamide. The International Bureau for Standardization of Man-Made Fibers (BISFA) classifies these fibers as man-made organic fibers obtained from synthetic polymers. All these fibers are expected to get a share of around USD 6.5 billion till 2024. Polymeric fibers are used in different forms for getting higher performance in different environments, Geotechnical hydraulic applications [31]. Polyethylene is the oldest one discovered by ICI in 1931. Polyamides were discovered in 1935 but they acquired inferior qualities than polyester, discovered in 1941. Polypropylene is known to be most recent among these four [32]. The essential properties required in geotextiles are their mechanical properties, ability of filtration, and their chemical inertness. Polyolefins (polyethylene and polypropylene) are the most widely used synthetic fibers for geotextile applications along with polyester. Although there are other synthetic polymeric fibers but they are either costly or not viable in large quantities [33]. In 2012, it was estimated that 90 percent of synthetic geotextiles were polypropylene based, 5 percent polyethylene based and the rest were polyester based [3]. Table 7.3 provides comparison of properties of mainly used polymers for geotextile applications [34].

7.3.1 Polyolefins

Among different synthetic fibers used in geotextiles Polypropylene (PP) fiber belongs to polyolefin family a kind of hydrocarbon. Polypropylene fiber finds diverse applications in technical textiles particularly in geotextiles because of high resistance to different chemicals and higher permeability characteristics which help to prevent erosion, waterlogging and offer higher stable grounds [35]. Soil erosion seems to be a great hazard for earthworks especially on sloping grounds. The real focus of

Table 7.3 Comparison of mainly used polymers for geotextile applications

Comparative property	Polymer group			
	Polyester	Polyamide	Polypropylene	Polyethylene
Strength	1	2	3	3
Elastic modulus	1	2	3	3
Strain at failure	2	2	1	1
Creep	3	2	1	1
Unit weight	1	2	3	3
Resistant to UV stabilized	1	2	1	1
Resistance to UV unstabilized	1	2	2	3
Alkalies	3	1	1	1
Fungus, vermin, insects	2	2	2	1

1 = High; 2 = Moderate; 3 = Low

engineers in controlling soil erosion is holding the soil in place against water flow and floods. Polypropylene fiber can be used in different ways like fiber form or fabric form for controlling soil erosion. However, mostly PP fiber is used for soil erosion control either by mixing it with cement, clay, and spraying the cement mixture on required soil or preparation of polypropylene-based geotextiles with desired characteristics to hold fines while passing away from the upper layer of clay [36]. In one study by M. Dafalla showed that fiber reinforced grout was found to reduce soil erosion from 86% to 68% through elimination or reduction of cracking and loss of erosion by generating slack contact lines between soil and reinforcing fibers.

Applications

Polypropylene was first used by the Dutch to weave heavy steel wires into polypropylene textiles to be used in land reclamation drives at coastal lands [33]. It is also used as artificial grass, in caselon playing fields. It is made up of light resistant polypropylene with carboxylated latex backing pile up to 2.5 cm high [32]. In geocomposite drains, polyolefins are used as core material [37]. Both Polypropylene and Polyethylene are used in manufacturing geogrids, embankment support, and soil reinforcement. Du Pont used heat bonded nonwoven fabrics made from continuous filament polypropylene, for carpet backing for unpaved road applications [33]. Woven geotextiles tubes made from polypropylene are used in marine engineering applications as a breakwater [37]. Polypropylene geotextiles with strength in the range of 100 to 200 kN/m are used as basal filters. Both polypropylene and polyethylene are used in manufacturing artificial grass [32].

Polypropylene is also used in filtration applications. Geotextile filters are further subdivided on the basis of fabrication techniques like knitted, woven, and nonwovens. For applications where high tensile strength is required nonwovens are not used. These are used when robustness, deformation capability, and porosity are required [35]. Bituminous impregnated nonwoven geotextiles increase service life of roads through delayed reflective cracking. However, the magnitude of improvement depends upon the right installation of fabrics in road construction and re-pavement [38]. Polypropylene nonwoven fabrics provide best puncture protection for geomembranes in comparison to polyester. Nonwovens made of PP have better puncture resistance than PET based nonwovens. PP based needle punched nonwovens have, approximately, 100% higher resistance for pin puncture, 35% higher resistance for pyramid puncture and 25% higher resistance for CBR puncture [39].

Polypropylene-based needle punched nonwovens are also used in water permeability applications in geotextiles. The cross-sectional water permeability depends upon the pore size of polypropylene needle punched nonwoven [40].

Advantages and Disadvantages

Some advantages and disadvantages of polypropylene fibers are given below:

- Chemically inert.
- Swell by organic solvent.
- Not attacked by microorganisms.
- Susceptible to creep due to low glass transition temperature (T_g)
- It is the lightest material used for geotextiles which are also lighter than water [37].
- Jute–polypropylene blend geotextile matting has improved durability.
- Polyolefins may get degraded when react with oxygen.
- Environmental aging reduces strength of PP-based geotextiles while soil buried and underwater aging have no significant effect on tensile strength of PP woven geotextiles [41].

Some advantages and disadvantages of polyethylene fibers are given below:

- Chemically inert.
- Swell by organic solvent.
- Not attacked by microorganisms.
- Raw polyethylene is colorless and suffers light degradation [37].
- The addition of carbon black stabilizer makes it more resistant to light.
- Lack of supply of polyethylene fibers puts a limit on its usage is geotextiles.

7.3.2 Polyester

Polyester is one of the most commonly used man-made fiber along with nylon. It was first developed in 1941 and after that it has been used in vast applications in all most all types of textiles. However, in technical textiles, the reason for using polyester is its high strength, durability, and low cost.

Applications

It was first used by the Dutch to weave heavy steel wires into polypropylene textiles to be used in land reclamation drives at coastal lands. Nonwoven geotextiles made from polyester are also used for separation and filtration [33]. AstroTurf used in sports is made by knitting nylon6,6 piles into polyester yarn backing due to its high strength [32]. Woven polyester geotextiles are used for geogrids, embankment support, and soil reinforcement. Monsanto Textiles Co. developed polyester spun-bonded nonwoven for railroad application. These are also used in geocomposite drains as a filter material [37]. Woven polyester geotextiles are used as a basal reinforcement with sand fill on its top [3].

Polyester nonwoven geotextiles are used in earth systems to model transient water flow. At a given suction the amount of water contained is more in drying process, as compared to wetting process. Moreover, they are more hydrophobic in the in-plane direction as compared to across the plane direction [31]. PET based needle punched nonwoven geotextiles are used as a puncture resistant layer over geomembranes in civil applications [39]. Thanks to the high tenacity and lower elongation properties of polyester, it is also suitable for roofing application due to its ability to face higher tensile, flexural stresses, bursting stress. For the like reasons it is also considered fit for tidal barrage protective devices as well [42].

Advantages and Disadvantages

- High strength, creep resistant, and chemically inert.
- Resistant to UV radiations.
- Optimum balance of cost versus performance.
- Not recommended for application in pH higher than 9.

PET based geotextiles face hydrolytic degradation above glass transition temperature. This occurs with reduced tensile strength, elongation, decreased viscosity, and/or increased brittleness. Aging causes stiffness in PET based geotextiles [7].

7.3.3 Polyamide

Polyamides were discovered in 1935 but they acquired inferior qualities than polyester and Polypropylene. That’s why it has very less applications in geotextiles [32].

Advantages and Disadvantages

- Resistant to abrasion.
- Prone to hydrolysis.
- Gets soften once exposed to water.
- More strength but less moduli in comparison to polyester and polypropylene.
- Inferior cost to performance ratio in comparison to polyester.

Geotextiles made with polyester exhibit good resistance to organic acids and solvents. Also, they are resistant to bitumen and petroleum. However, they are susceptible to hydrolysis under alkaline conditions. The soil environment hardly exceeds pH

10. The calcium ions are an exception which increases the rate of alkaline hydrolysis tremendously. That is why polyester strength is expected to decrease greatly under hard water conditions. Table 7.4 presents the behavior of various geotextiles under soil burial environment [43]. Generally polyester and polyamide have moderate resistance to UV radiations. The sensitivity of polyester may decrease or increase depending upon the type of delustering agent, dyestuff, and other additives.

Table 7.4 Behavior of synthetic geotextiles under soil burial environment

Fiber Type	Fabric structure	Duration (years)	Soil type/location	Effect
Polyester	Woven	2–7	pH 4.7–11.5	5–15% strength loss
	Nonwoven	15	pH 9–10	12–40% strength loss
	Woven	17		Insignificant
	Woven	1	Peat	Up to 30% strength loss
	Nonwoven	7	Organic soil	Negligible
	Woven	3.3	PFA/water pH8.7	3–6% strength loss
			pH 11.9	4–7% strength loss
	Nonwoven	1–6	Drainage	0–26% strength loss
Polypropylene	Nonwoven	4–6	pH 4.7–11.5	Up to 30% strength loss
	Woven	7	Water/bank interface	15% strength loss
	Woven	1	Peat	Up to 30% strength loss
	Woven	5–6	Permanent edge	20–30% strength/extension loss
	Nonwoven	7	Organic soil	Negligible
	Nonwoven	10	Railway separation	20% strength loss
			Erosion protection	8% strength loss
Polyamide	Woven	7	Water/bank interface	30% strength loss
	Woven	1	Peat	Up to 30%
	Woven	10	Sea water	About 20% strength loss
	Woven	15	Bank mattress	35–60% strength loss upper surface
				3–30% strength loss lower surface

7.4 High Performance Fibers

Nowadays focus of geotextiles is mainly toward the usage of synthetic fibers and natural fibers as explained in Sect. 7.2 and 7.3. While the high performance fibers are limited in application because of non-availability in huge amount as well as the high price of these fibers. However, the induction of high performance fibers in the field of geotextiles can bring a revolution because these fibers are different from conventional synthetic and natural fibers in terms of tenacity and modulus. That is why these fibers are also called high tenacity and high modulus fibers [44]. High performance fibers can be classified into three categories like chemical resistant fibers, heat resistant fibers, and high strength and high modulus fibers.

7.4.1 Carbon Fibers

Carbon materials find enormous applications in geotextiles particularly where high strength and temperature tolerance are required because of their extraordinary thermal, electrical, and mechanical properties [45, 46]. Different people used different allotropes of carbon like carbon black, carbon fibers, graphene, and carbon nanotubes for improving the strength and ductility of geotextiles. It was found that the addition of such materials not only improves the mechanical properties of geotextile but also gives additional benefits like high-temperature bearing capacity because of high-temperature resistant nature of carbon materials [47, 48]. Another problem is the effect of weathering conditions which play a significant role in the deteriorating strength of geotextiles. The use of stabilized carbon-based materials helps in preventing the weathering effect and increases life span of materials to be used in geotextiles [49].

Since carbon fibers are devoid of porosity and have a very limited surface area so they are not used directly for filtration purposes. However, geotextiles used for drainage purposes require a high strength side by side adsorption characteristics. Hence carbon fiber is used as a backing material in filtration cloth for getting mechanical stability and durability [50].

However, another allotrope of carbon, i.e., activated carbon is more popularly used in air and water filtration purposes. Around 80% of produced activated carbon worldwide is used in water filtration while 20% is used in air filtration, sound absorption, and odor adsorption along with other applications. Activated carbon is widely characterized for high surface area, porosity, and presence of different functional groups. Nowadays activated carbon prepared in different forms like activated carbon powered, activated carbon fibers, activated carbon cloth, activated carbon webs and the trend is shifting toward the development of nanofibrous membranes by using carbon materials. There are different precursor materials like Polyacrylonitrile, cellulosic materials, and different textile waste materials are being employed for getting required surface area and porosity.

7.4.2 Aramid Fibers

The primary function of geotextiles in civil engineering is to provide reinforcement of soil or building structure. Good quality concrete materials are regarded as the backbone of civil engineering. The trend of modern construction toward megastructures and skyscrapers has pushed civil and material engineers to think on these lines. In this context the use of synthetic fibers is a good option but high performance fibers dominate when special high-end applications are required. Kevlar and Twaron are most common para-aramid fibers. Kevlar fiber reinforced concrete (FRC) materials are being considered as one of the most versatile materials which not only act as crack arrester but also try to restrict further growth of defects in a matrix that can cause failure under huge loading conditions. These fibers have high strength to weight ratio further their amazing busting strength and less brittle nature makes them ideal to be used in geotextiles. Different researchers have found that the addition of para-aramid fibers in concrete results in less bleeding of concrete material, higher tensile, compressive, and flexural strength.

Since para-aramid fibers are very expensive fibers hence researchers are trying to use recycled Kevlar or other para-aramid fibers for enhancing mechanical properties of geotextiles [51]. During usage of geotextiles in soil layering side high strength along with high level of bursting strength is also required because of possible presence of sharp objects in soil. Since these fibers have extraordinary busting strength and inherent puncture-resistant characteristics so they are preferred choice while using as soil reinforcement [49, 52].

Synthetic materials like polyethylene suffer from premature aging in alkaline climate because of which alternate materials are being tried for soil reinforcement. In alkaline environment, Technora aramid fibers offer an alternate solution which was previously used in composites, cables, and ropes [53]. As far as durability of Technora fiber in alkaline medium is concerned, it was found that it offers better aging conditions and higher mechanical properties as compared with polyester fiber and other synthetic materials which are hydrolytically less resistant.

7.4.3 Glass Fiber

The stability of soil is among one of the significant areas in geotextiles. Soil stability can be lost due to a number of reasons on ground level or in slope from which results in loss of economy and life. A different technique is being employed for soil preservation and stabilization out of which fiber reinforcement is getting attraction because the presence of the random orientation of flexible fibrous structure helps in imparting stability and strength to soil layers. This technique is already in use for maintenance of thin layers in soil, strengthening of soil as well as revamping failed slopes [54]. Some researchers claimed that effective use of polyester and polypropylene fibers can reduce the development and propagation of cracks in the soil, improves the strength of soil as well as cemented sand [55, 56]. However, by using glass fibers in the soil its plastic limit and liquid limit increased while plastic index was reduced, which indicates reduction incompressibility of soil [57].

Side by side with its application in soil separation glass fibers are also used as reinforcing material in concrete for better properties in terms of higher mechanical properties and better stability. Although glass reinforcing concrete materials do not offer high mechanical properties because of this reason its use as reinforcing material in concrete is very limited. Nevertheless, they offer several advantages over traditional concrete like higher service life as compared with conventional concrete materials, environment friendly, fire resistant, resistance to strains, and lighter in weight [58]. However, researchers are in search to investigate different mechanisms in order to increase mechanical strength of fiber reinforced concrete materials.

7.4.4 Basalt Fiber

The raw material of basalt fiber is naturally occurring volcanic which comprises on silicon dioxide. The continuous fibers of basalt are prepared by melting which have high-temperature bearing capacity and alkali and acid resistant [59]. Basalt fiber has wide applications in filter material, for high thermal insulation, higher mechanical stability in composites, deafening materials, civil and military applications, and geotextiles [60].

The trend of fiber reinforced concrete is getting popular in the architectural industry because of higher mechanical properties, corrosion resistance, light weight, and high-temperature resistance. Currently, carbon fibers, aramid fibers, and glass fibers are more commonly used as reinforcing materials. Carbon fibers when used as a reinforcing material offer ten times more strength as compared with ordinary steel. While Basalt fiber also offers high strength around 600–1500 Mpa and corrosion resistant nature and has the potential to replace carbon fiber reinforced structures. The additional advantage of basalt fiber is its low cost of manufacturing and cheap price as compared with carbon fibers. In this regard C. Feng showed that by addition of basalt fibers substantially increases cohesion characteristics of cement soil. He further confirmed that addition of basalt fibers in the cement can substantially increase plastic deformation and mechanical characteristics of cement soil. Z Guo further showed that surface modification of basalt fibers by using different alkali treatment methods can further enhance its compatibility with different matrix materials for getting better mechanical properties [61]. On the whole basalt fibers offers high stiffness and mechanical properties with long-term durability, high-temperature resistance, solvent, and acid resistance, good sound damping properties, easy and cheap fabrication process, eco-compatible, and recyclable which make them attractive choice to be used in geotextiles [62].

7.4.5 *Aromatic Polyimides*

The most widely and oldest use of geotextiles is probably for filtration purposes. Geotextile filters are designed in such a way that they allow liquid to pass through the material or plane of the fabric however blocking the flow of solid materials and particles which shows that geotextile materials used for filtration purposes should have optimum levels of pore size which can trap solid particles, however, it should have sufficient permeability that allows the movement of fluid. There is no doubt that textile materials have these attributes to meet these requirements and are suitable for use as a filtration medium in geotextiles. However, when the geotextiles will be used for drainage purpose then side by side with filtration abilities filter material has to bear extra pressure because of surrounding soil.

7.5 Conclusion

Geotextiles are a promising area which is becoming popular in developed and developing regions simultaneously. Natural fibers have a major share in the development of geotextiles for different applications like construction of buildings and megastructure, separation of different kinds of soil, filtration, and sealing. The usage of natural fibers in geotextiles is preferred in terms of economic and technical grounds. However, mainly sisal, jute, and coir fibers are dominating in geotextiles [63]. However, natural fibers offer some disadvantages like low mechanical strength, biodegradable, durability issues, poor resistance against acids and bases, moisture absorption characteristics. These drawbacks pushed researchers and scientists to use different synthetic materials. Polyester, polyamides, and polypropylene are widely used in the manufacturing of geotextiles for different applications. The synthetic fibers are used in fiber woven or knitted form according to the application area. However, in different areas the concept of high performance fibers is gaining importance because of their extraordinary high performance in geotextiles.

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Chapter 8
Fibers for Agro Textiles

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Abstract Agro textile is a vital and developing area among all the areas of technical textiles. It covers products from fishing to horticulture and husbandry application. The significance of the agro textiles is considered as an important area all over the world. There are various applications of agro textile products that have shown great results and have a positive effect on production and growth of numerous vegetables and crops. The purpose of this chapter is to give an overview and significance of agro textile products that can be used in various applications to enhance the yield of crops. Agro textile products provide the adequate humidity to soil, maintain the temperature, and protect the products of crops from the hail. Agro textile products like bird net, harvesting net, sunscreen, windshield, hail protection net, mulch mat, etc. are getting much attention these days. Natural fiber based agro textiles can be used in those specific areas where wet strength, moisture retention, and biodegradability are required. Polyolefin fibers are preferred among all the man-made fibers for agro textile products due to high strength, light weight, and long service life. Another intention of this chapter is to make the readers comprehend about this area and to encourage them to use agricultural products for enhancement of yield.

Textiles used in the agriculture sector are known as Agro textile. The most ancient profession of mankind is Agriculture and at present it is one of the major global industries. Agro textiles have its application in agriculture, fishing segments, horticulture, landscapes, animal husbandry, agro engineering, forestry, gardening, floriculture, and aquaculture. The products of agro textile can be knitted, woven, or nonwoven and has application in agriculture, such as fishing net, shade cloth, mulch mat, etc. [5]. Agro textiles have significant importance due to its applications. It harvests the production, helps to increase plant height, shields the crops from climate, and reduces

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the fertilizers or pesticide requirements. It helps to prevent the soil from drying and also enhances the product quality [1].

Agriculture has been growing to meet the world's food requirement. There are more than 800 million communities which have food insecurity and the food outlook is in doubt. Ecological degradation, climatic alteration, high energy charge, and increasing competition for land and water are enormous challenges and danger. For example, to meet the demand the production of cereal should increase nearly 50% up to 2030. So for this purpose Agro textiles can play an important role to meet the world's requirement. Agro textiles control the drying of the soil and increase the crop yield. It also improves the fruit's freshness and gives value to consumers and farmers to earn their money by increasing the quality of the product. It protects the farmers from injurious pesticides. Ultraviolet stabilization provided by the thermal-protected textiles. Thermal screens and shade netting can save the 40% energy in heating greenhouses. Its use can enhance the fruit's quality prevents the staining and provides the color uniformity. The agro textiles can also be used to prevent the growth of weeds which are injurious to agriculture. There are several factors affecting the agricultural activities such as sunshine (direct and indirect), hail, wind humidity, birds, insects, wild plants, and most important water.

The use of textile materials in agriculture is rising fast. Textile materials in different forms like knitted, woven, nonwoven, twine, knotted, braided, etc., can be used for different applications. Woven and nonwoven mostly used for mulch mats, sapling bags, shades, ground covers; knitted structures are used for packaging materials, screens, and nets; while knotting technique especially used for fishing nets. There are some properties that make the textile suitable to be used as agro textile such as long service life, easy transport, biodegradability, protection property, performance ratio, High potential to retain water, resistance to ultraviolet radiations, and space-saving storage.

Agro textile can be categorized according to the application area and these areas are as follows:

- Agro textiles for aquaculture and animal husbandry
- Agro textile for crop production
- Agro textiles for floriculture, forestry, and horticulture.
- Agro textiles for agro engineering-related applications

Natural, synthetic, and high performance fibers utilized in development of technical textiles. This chapter attempts to discuss fibers under different categories which highlight their importance and their scope. The discussion introduces the fibers, their applications in agro textiles and their advantages and disadvantages.

8.1 Natural Fibers

Natural fibers from animals and plants have been used since ancient times for the traditional and technical applications. The cloth manufacturing is a traditional use of fibers and the industrial revolution began with the development of machines and different looms for the quick production of clothes as compared to production from hand. In the prehistoric days, there are some other uses of natural fibers such as cords, bowstrings, sail clothes, and ropes which show their applications in technical way. The plant fibers are made up of cellulose molecules embedded in the matrix material [16]. Cellulose is a polysaccharide, constituting the polymeric carbohydrate molecules and is a complex naturally occurring polymer which forms the basis of the plants [18]. Fibers such as jute, cotton, hemp, and Flax derived from plants [6, 15]. Animal fibers extracted from the hair of animals like wool from sheep and cashmere from camels, goats, and alpacas, but there are some other fibers like silk, which are not extracted from mammals.

Jute is the natural technical fiber, mainly used in agro textile due to a good strength and biodegradability. It is used either in woven or nonwoven form to achieve higher productivity in agriculture through improving agronomical properties and by decreasing the unwanted vegetation growth [25]. Coir fiber is preferred to agricultural use due to its very good characteristic of moisture retention [23]. It is resistant to moulds, rot, and moisture [12, 28]. Coir fiber can be used in the fiber form or by making a desired product which imparts the specific needs [2]. Coir fiber can be converted to yarn and into mesh matting for controlling soil erosion and soil conditioning. The same properties can also be achieved by converting coir fiber into nonwoven sheets. Wool fiber under the moist condition has insulation properties [3] which can prevent the damage to seedling from ground frost and enables the longer growing season [8]. Wool keeps the temperature of the soil constant [13] and can be compared with black plastic which cannot provide wind tunnel effect and soil gets dry [20–22]. The other natural fiber like sisal and hemp mainly used to make the protection nets for vegetables. These fibers are mostly used for the crop wrapping [29].

8.2 Applications

Mulch mats

Jute is widely used in the formation of mulch mats. These mulch mats are used to decrease the weed growth in horticulture as shown in Fig. 8.1. Weed control has been achieved traditionally using bark chips which protect the soil, light blockage, and suppress the weed growth from all over the seedlings, but has the disadvantages that it cannot provide the air tunnels to the plants. Coir and wool nonwovens are also used effectively for the formation of mulch mats. These mulch mats provide air and water tunnels to the plants and at the same time block the light and prevent the weed growth from the seedlings.

Sleeve for nursery use

Woven fabrics of jute or braided sapling bags are used to form sleeves in nursery [11] as given in Fig. 8.2. The jute fabrics and braid sleeves can circulate the water and

Fig. 8.1 Mulch mat

air inside which can stimulate the plant growth. For this purpose, polythene sleeves were used in nurseries but it had disadvantages. The poly sleeves are torn out after transplantation of grown-up plants and thrown away on the ground which creates pollution. During tearing of polythene bags there is a chance of damaging of root network. The air and water circulation are also affected. The inherent properties of jute are the solution of such problems. The porous structure of the woven and braided sleeves can circulate the air and water inside the sleeves and thus stimulate the plant growth.

Packing material

Jute has been used for packaging material since 1973. It is inexpensive and renewable natural fiber, which is used abundantly in the subcontinent for packaging material [14]. Because of its good tensile strength and excellent frictional properties made it most widely used material for packing as shown in Fig. 8.3. Various agriculture products such as spices, grains, sugars, and vegetables packed in jute bags locally and globally.

Erosion control blankets

The mesh made up of coir fibers acts as small dam and protects the seeds or seedlings from washing away by rainwater and wind. The netting breaks down in dissipating the energy of water flow due to heavy rains. When the vegetable grows, the function of coir fiber ended because this growing vegetation is enough to protect the soil further. Blankets made of nonwoven shown in Fig. 8.4 are enough to protect the ground from erosion and creates mulching action.

Fig. 8.2 Seedling planted jute braided sapling bag

Fig. 8.3 Jute as packing material

Fig. 8.4 Coir erosion control blanket

Mulch blankets

The nonwovens or woven matting of coir perform filtration of water and allow the water to flow its plane and separator. These blankets suppress the weeds and keep the soil moisture that will save the roots from winter frosts (Fig. 8.5).

Plant bed blankets

Bed blankets made up of coir fiber for seed germination are the supreme choice for the germination of seed and have been used in aquatic spawning, wetland restoration, construction sediment traps, and floating islands. The roots of the plants remain moist in dry weather because it has the ability to hold the water. It is ecofriendly and cost-effective solution because it is 100% natural and biodegradable.

Basket liners

The coir basket liners are used for the hanging purpose of baskets. These pads provide better airflow of growing substance. Coir pads have pores from which air can easily flow, which helps the roots to grow vigorously. Felt of coir nonwoven cut in various shapes depends on the size of the wire basket known as basket liners.

Bio rolls

Bio rolls are used in the plant to achieve the rapid growth of roots. Felt mats produced from coir fiber in the form of rolls which then filled with moss/coir pith and used as bio rolls.

Roof green mats

Coir nonwoven felt are used in roof greening mats which are then spread by seeds or seeds laid with stitched coir pads. These green mats spread on the surface of the

Fig. 8.5 Coir mulch blankets

roof and the seeds sprout out on these chair pads which then grow consistently on the surface.

Grow sticks

The plants and creepers are supported by grow sticks. Grow sticks are the wooden pole enveloped with a coir fiber layer or nonwoven felt. The plant roots can penetrate on the coir pad pores.

Baler twines

These baler twines are made up of hemp and sisal used in the grape yard for tying purposes. These twines are basically stronger threads composed of many smaller threads or strands which are twisted together and primarily used for crop wrapping. These twines also use din plantation of tomato and for all heavy vegetables and fruits to hold them on their stem or branch.

Udder protection nets

These nets made of cotton or its blend and used for the protection of udder from any damage in the pasture and in crowded barns as shown in Fig. 8.6. It also used to protect the udder from step injuries.

Fig. 8.6 Udder Protection net

Advantages

- It has high moisture retention.
- It gets strengthened when absorb water.
- It is biodegradable, sustainable, and ecofriendly.
- It is not harmful to the environment.
- It is resistant to fire, but some fibers melt on exposure to fire.

Disadvantages

- It has a high manufacturing cost.
- It is not available as high strength or high tenacity fiber.
- It is not resilient.
- Its production is not controllable.
- It has variation in length and fineness.
- It is affected by natural climates.
- Its production requires land.

Synthetic Fibers

Polyolefin fibers are mostly used among all the synthetic fibers in agriculture applications while polyester and nylon are in lesser quantities. Synthetic fibers have high strength, excellent durability, and other characteristics make them suitable for agriculture applications [17]. On the other hand natural fibers that are used in agriculture can serve particular performance and are degraded after some years which can act as fertilizers. Synthetic fibers are usually preferred over natural fibers due to some reasons, mainly long service life, lightweight with high strength and price performance ratio. But natural fibers can be used in that area where properties like wet strength, moisture retention, and biodegradability are required.

Polyester

Polyester fiber, which has chemical name polyethylene terephthalate (PET) overcomes the textile synthetic fiber industry [1]. They can easily be produced from petrochemical sources and are inexpensive having good physical properties. They are lightweight, strong, wrinkle resistant, easily dyeable, and have good washing fastness properties. It is used in numerous textile applications in fiber and filament form such as furnishing, household fabrics, and apparels. Micro polyester is mainly used for sportswear or outdoor wear. It is used in car seat belts, industrial fibers, carpets, filter clothes, sail clothes, tire cord, tentage fabrics, and so on. There are some other types such as PBT (polybutylene terephthalate) and PTT (trimethylene terephthalate) that are using specially in carpets because of their good resilience property. Biodegradable polyester used for medical applications (drug delivery, dissolvable sutures) and is derived from lactic acid and glycolic acid.

Nylon

Nylon is the only synthetic fiber that had full-scale production before World War 2. The development starts in 1928 within the work of Wallace Carothers working with DuPont in USA [9]. In 1935 nylon 6, 6 polymers had been produced for the first time and production starts in 1938. Nylon fibers sent to production in the same year and sale in October in 1939. The production of nylon starts in the UK under the license terms with DuPont with British nylon spinning in 1941 [10]. Mostly nylon fiber was produced in World War 2 for military use specially used for parachutes. After that it sold for domestic purpose in 1946. At the same time the production of this fiber starts in Germany in 1931 as nylon 6 rather than nylon 6, 6 [26, 27].

Carothers developed domains from 2 to 18 carbon atoms and react to them different carboxylic decides for the valuation of polyamides (Patent No. 2,071,250, n.d.) [4]. Total world production of synthetic fibers was 69000 tons in 1950 and it was almost nylon fiber. After 20 years, some other synthetic fibers have been developed and produced such as acrylic, polyester, polypropylene, etc., and volume increased up to 4.8×10^6 tons and 40% was nylon [7]. Nylon was always the most important synthetic fiber in volume terms. The applications have extended from the hosiery market to rubber, belts, and tire markets. It also had some other applications such as bed sheets, shirts, underwear, and other apparel [24].

Polyolefin fibers

Polyolefin fibers are those fibers whose polymer chains comprise saturated aliphatic hydrocarbons of high molar mass. The US federal trade commission accepts names polyolefin fibers and Olefin fibers for those fibers that are manufactured with at least 85% by mass of polyolefin [19]. Among the polyolefin fibers polypropylene (PP) has the industrial importance, but polyethylene (PE) has less importance as compared to PP. Both these fibers are recognized as generic names defined by ISO2076. The correct names of PE and PP are polyethylene and polypropylene. There are some other polyolefin fibers that have commercial importance such as poly 1-butene, poly 4-methyle-1-penten, and poly 3-methyl-1-butene. These fibers also used in blends in commercial applications like bicomponent filament yarns in which PE is sheath and PP is core. When this type of fiber heated, the sheath of PE melts and bonds the multifilament into monofilament yarns. These fibers can also be used for the other polymers like polyester and nylon.

8.3 Applications

Shade Nets

These are basically nets made up of polypropylene or polyethylene fibers with several shade percentages. These nets control the environment by controlling the light intensity and heat during the day to crops growing beneath it as given in Fig. 8.7. The use of shade net can increase the cultivation season and off season cultivation depends upon the crop type. These are shade net houses providing a frame structure formed by angle iron, bamboo, wood, and GI pipes and then enveloped with nets. Since each plant has its own requirement of shade and sunlight upon which it efficiently grows. To provide the optimum conditions of climate, the selection shade percentage plays a very important role to increase the plant productivity. Shade nets are accessible in several shade factors or shade percentages ranging from 15–90%. 15% shade percentage means the net will block the 15% intensity of light and allow 85% of light to pass through the net. Three percentages 35, 50, and 75% are most commonly used in agriculture sector.

Packing Material

Polypropylene bags are the toughest packing bags which are mostly used for the grain, sugar, and milling industry. These bags also have wider applications in chemicals, fertilizers, and fodder industry.

Insect meshes

These meshes are made up of polyethylene and nylon used to keep the pollinating insects within the mesh so that pollinating phenomenon can occur in an efficient way

Fig. 8.7 Shade nets in agriculture

as shown in Fig. 8.8. It also prevents the harmful insects entering into the tunnels or greenhouses. This mesh does not require any insecticide to protect the plants from harmful insects.

Cold and frost control fabrics

Polypropylene fiber is used to develop the cold and frost fabric. The purpose of this fabric is to create a good microclimate which absorbs the additional heat during the day and also control the heat loss at night from the soil. This fabric downs in the low temperature without harming the plants (Fig. 8.9).

Weed control fabric

Polyethylene fiber used for the fabrication of weed control fabric. This fabric is used to control the growth of weed. These fabrics are nonwoven and manufactured using needle punching technique.

Fig. 8.8 Insect mesh

Fig. 8.9 Cold and frost control fabric

Fig. 8.10 Net for covering pellets

Net for covering pellets
These nets are made from polyester, nylon, or polyethylene and used as packing material for delivering the agricultural goods to the market as given in Fig. 8.10. The purposes of these nets are the protection of vegetables or fruits from damaging during transportation. The boxes are covered with large pellets or nets to prevent the damage during transportation as shown in Fig. 8.10.

Antifouling nets
These nets are made up of nylon which provides a physical blockage of biofouling as shown in Fig. 8.11. These nets have longer lifetime because it has good wear and tear resistance in saltwater than fishing nets.

Mosquito protection nets
These nets are made up of nylon and used to protect the cattle from mosquitos and harmful insects as shown in Fig. 8.12.

Anti-hailstone net
Polyethylene filament fibers used to produce the anti-hailstone net for the protection of cultivation from hail damages (Fig. 8.13).

Support nets
These are nets made from nylon and function of these nets is to support the climbing vines and the plants growing vertically. These nets also support flowers growing and large fruits to grip in the plant.

Ground Cover
The ground covers are made up of polypropylene used for the long-term control of weed and reservation of moisture. These are mostly used in horticulture and landscaping.

Rain protection fabric
Rain protection fabrics are made from polyethylene and protect the cultivations like tomato from rainfall.

Fig. 8.11 Antifouling nets

Fig. 8.12 Mosquito protection net

Bird Protection net

Nylon, PE, and PP fibers are used to make the bird protection net. The purpose of this net is to protect the crops, fruits, and seeds from damage because of birds or other pests. The mesh size of the net should be large enough to movement of bees.

Advantages

Fig. 8.13 Anti-hailstone nets

- It is strong, i.e., has good strength and tenacity which can easily take heavy things.
- It has good elasticity and durability.
- It has good ability of drying because of its hydrophobic nature.
- It is lightweight and cheaper than natural fibers because it has less manufacturing cost.
- It is not affected by water, chemical, or bacteria.

Disadvantages

- It is non-biodegradable and not ecofriendly.
- It is harmful to the environment.
- It does not absorb moisture.
- It burns easily.

High Performance Fibers

Ultra-High-Molecular-weight polyethylene (UHMWPE)
The fibers are very strong and have ultrahigh modulus based on a simple polyethylene molecule. Various terms are used for this fiber, such as high performance polyethylene fibers, lightweight polyethylene fibers, extended chain polyethylene fibers, and high modulus polyethylene fibers. It has a very high weight base performance due to its lightweight and good mechanical properties. Its fatigue properties are very high, but have a limitation that it has a low melting point. At present this fiber is widely used in various fields such as ballistic protection, marine, sports, protective clothing, etc. These fibers are produced using polyethylene $(\text{-}CH_2\text{-})_n$ with high molecular weight $M_w > 10^6$ g mol^{-1}. These fibrous chemicals relate to the simple polyethylene fiber, but its molecular weight is very high as compared to simple polyethylene fibers. UHMWPE fibers have the same chemical properties as polyethylene but it has major differences in mechanical properties due to fiber stretching and high orientation and crystallinity. There is weak intermolecular foces present between the molecular

chains of the fiber make the fiber, less strong in the transverse direction, but this property can be enhanced by branching of polymer.

8.4 Applications

Monofil nets
Knitted Monofil nets made up of UHMWPE used of the windbreak fences and shading screens. This windbreak sheet placed at right angle to the wind, which will then protect the plants against the damaging effects of the blustery weather.

Harvesting nets
These nets used to protect the fruits that are susceptible to darkened kernels, bug invasion, mold infections, or insect invasion due to the laying on ground as given in Fig. 8.14. This net makes the harvesting sustainable, clean, and easier. It also reduced the fruit collection time.

Aquaculture nets
These nets are used for the cultivation of various types of fish in the pond. It is specially used for the cultivation of normal fish with the predatory fish or cultivation of different size fish in a lake or pond. The aquaculture net made of UHMWPE is shown in Fig. 8.15.

Fishing nets
Fishing nets as shown in Fig. 8.16 are basically knitted fabrics made up of UHMWPE used for fishing because it has high tenacity and breaking strength.

Fig. 8.14 Harvesting nets

Fig. 8.15 Aquaculture net

Fig. 8.16 Fishing net

Advantages

- It has very high strength and high modulus.
- It has excellent durability characteristics that make them suitable for aggressive environment.
- It has good creep property.
- It has good chemical resistance.

Disadvantages

- It has poor fire resistance.
- It is sensitive to sunlight and oxygen.
- It has poor compressive strength.

- It loses strength at high temperature.

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Chapter 9
Fibres for Medical Textiles

Ali Afzal, Usman Zubair, Muddasara Saeed, Munazza Afzal, and Arusha Azeem

Abstract This chapter is focused on the application of textile fibres in medical field. The fibre properties which are required to classify them as medical fibre are explained in detail. A number of different textile fibres including natural, synthetic as well as application-based textile materials are explained with the requisite properties. The fibre properties, advantages and disadvantage of the fibres and biocompatibility for medical purposes for various textile materials are explained in detail. The chapter is beneficial for basic as well as detailed review of materials for medical applications.

9.1 Introduction

The future of fiber technology for medical textile and applications fundamentally depends on the future requirements of our civilization. It has been said that unmet needs drive the funding that sparks ideas. The field of medical science includes a broad range of natural and synthetic textiles, medical devices; creating innovative products to meet the unmet needs in the rapidly growing fibre market. Medical textiles provide the foundation for modern medical technology products of the future. In this

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regard new biofibre researches have been encouraged by the United States homeland security, resulting in the progress of antibacterial fibres used for clothing and filters to eliminate pathogens and enzyme-linked fibers to facilitate decontamination of neurotoxins from human skin. Magnetic fibres may also apply in future defence applications including fibre-based detectors for individual and substance identification. The trend of work in smart and interactive textiles is rising with a projected average yearly growth rate of 36% by 2009, moreover specific markets as medical textiles and enzymes will develop rapidly [1, 2].

The application of textile is not new in medical textiles, the combination of medical sciences and textile technology has resulted in a new branch known as medical textiles. The textile materials used in the medical field are polymers, regenerated fibres, yarns, woven, nonwoven and knitted fabrics. Medical, health care, and hygiene zones are the most expanding part of the industry. Medical application is one of the most rapidly growing part of the textile industry. Along with the passage of time, the medical sector is moving rapidly towards the manufacturing of textile products with high added value, including smart textiles, medical textiles and protective textiles [3, 4]. The textile raw materials (i.e. fibres) are essential for the development of medical textile products and medical devices [5]. The aim of this chapter is to understand the types of fibres used in the medical and surgical applications.

To date, many types of textile fibres are proposed and practiced in the field of medical textile. Similarly, the textile implantable devices, used in the modification of the surgical methodologies, are prepared by the medical textile market on a large scale. The fibre materials are engineered for their precise usage in both Interventional and surgical procedures [6]. Speciality fibres are specifically designed and developed for infection control management, wound dressing and life-saving risk management. Fibre application in medical textiles is illustrated in Fig. 9.1. Medical textiles sourced from technical textile are one of the developments which are really meaningful for patients that convert the painful days into comfortable days. The desired qualities of medical textiles include greater durability, flexibility, strength and bio-compatibility.

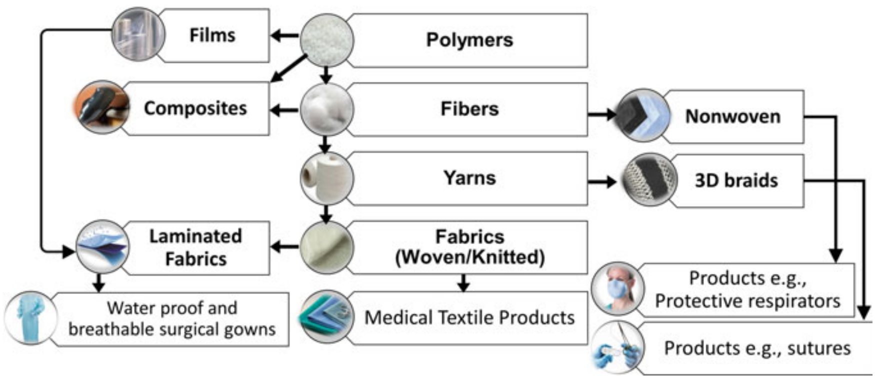

Fig. 9.1 Fibre application in medical textiles

9.2 The Properties Required for Medical Textile

The textile fibres used in the medical field have different properties anticipated for their benefits. Textile materials used in the medical field are fibre, yarn, fabric and composites. The global fibre consumption in medical textiles is increasing with the growing population of the world [7, 8]. Both natural (cotton, silk, and wool, etc.) and synthetic (polyester, rayon, etc.) Fibres are used in medical field and exhibit different properties/functions for the betterment of the medical field. The major function of medical textile products includes tenacity, softness, elasticity and biodegradability [4]. The main requirements are:

- Sterilized
- Non-allergic
- Physical/chemical properties
- Bio-degradability
- Nontoxicity
- Good dimensional stability
- Absorbency/Repellency
- Bio-compatibility
- Hygiene
- Strength
- Air permeability
- Elasticity
- Free from impurities

9.3 Classification of Medical Textiles and Fibres in-Use

Over the past quarter of a century, the designing of innovative fibres for use in healthcare textiles has improved rapidly. Four major areas of medical textiles such as implantable, non-implantable, extracorporeal devices and hygienic products have more improved by advance fibre designs [3, 9, 10].

9.3.1 Classification of Medical Fibres Based on Application

According to Rajendran [11] four categories of medical textiles can be distinguished.

- Extracorporeal devices, i.e. Artificial kidney, artificial liver
- Healthcare and Hygiene products, i.e. Blankets, caps, masks, cloths/wipes
- Implantable material, i.e. Sutures
- Non-implantable materials, i.e. Compression bandages, orthopaedic bandages

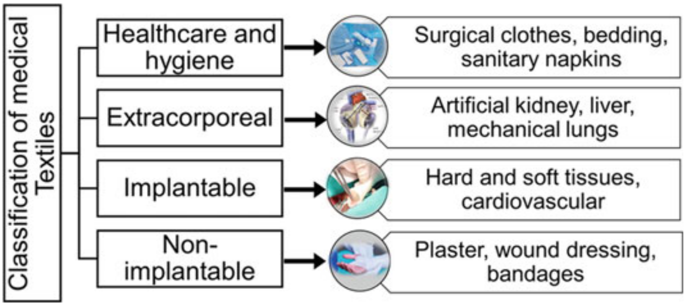

Fig. 9.2 Classification of medical textile based on application

The medical textile and healthcare products show a remarkable series of applications, from a simple bandage to antibacterial wound treatment, biocompatible implant, tissues and prosthetics [3]. Moreover, the categorization of medical textiles is given in Fig. 9.2.

9.3.2 Healthcare and Hygiene Products

Healthcare and hygiene sector is an important area of textile among other medical applications. Innovations and improvements in textile technology and medical procedures are providing a vast range of products for healthcare and hygiene (surgical gowns, caps and masks, patient drapes and cover cloths, Barrier material, Bagging and pressure garment), that must be washable or disposable (Table 9.1). Healthcare and hygiene products are sources from natural fibres such as cotton and silk and

Table 9.1 Application of fibres in Healthcare and Hygiene products

Fibre type	Fabric type	Application
Cotton, polyester	Woven, knitted	Beddings, pillow covers, blankets
Cotton, polyester, polypropylene, viscose rayon	Woven, Nonwoven	Surgical clotting, gowns
Viscose, viscose rayon, polypropylene, glass	Nonwoven	Caps, masks
Polyester, polyethylene	Woven, Nonwoven	Surgical cover, drapes cloth
Polyester, cotton, polypropylene	Woven, Nonwoven	Protective clothing
Polyethylene, polyester, polypropylene	Nonwoven	Incontinence diapers sheet, absorbent layer, outer layer
Elastomers	Nonwoven, knitted	Surgical hosiery

Table 9.2 Fibre application in extracorporeal devices

Fibre type	Application	Function
Hollow viscose	Artificial liver	Separate and dispose of the patient's plasma and supply fresh oxygen
Hollow polyester fibre, hollow viscose	Artificial kidney	Remove waste products from the patient's blood
Hollow polypropylene fibre, hollow silicone membrane	Mechanical lung	Remove carbon dioxide from the patient's blood and supply fresh oxygen

regenerated fibres such as viscose rayon because of their non-toxicity and non-allergic nature [13].

9.3.2.1 Extracorporeal Devices

Extracorporeal mounted devices are used to maintain the function of vital organs, such as lung, heart, liver, kidney. These mechanical organs including artificial liver, artificial kidney (dialyzers) and mechanical lungs are used to purify and oxygenate the blood. Artificial heart is an organ made of plastic to circulate the blood across the human body (Table 9.2) [12].

9.3.2.2 Implantable Material

Implantable medical textile materials, may or may not be bio-absorbable, are implanted in the human body. Textile-based implantable devices such as tissue scaffolds and suturesare mono or multifilament threads that are used to close wounds, tie off bleeding vessels, soft and hard tissues implant, vascular veins, biomaterial in ophthalmology, dental biomaterial, curing of wounds and burns, and for new applications used as artificial ligaments, artificial joints, heart valves, vascular grafts, artificial veins, artificial skin [14, 15]. The fibre application with respect to their structure is given in Table 9.3.

9.3.2.3 Non-implantable Materials

Non-implantable materials are used for peripheral application on the human body. The most common use of these materials is to create aseptic conditions for protection against infection. In addition, these materials absorb and prevent excess fluids and exudation of blood in the form of absorbent pads, wound dressings and bandages. Other non-implantable materials include braces/orthotics, plasters and fibre cast [15]. The fibres used for different applications are explained in Table 9.4

Table 9.3 Application of fibres in implantable materials

Fibre type	Fabric structure	Applications
Polylactide fibres, polyglycolide fibre, collagen	Monofilament, braided	Biodegradable sutures
Polyethylene fibre, polypropylene fibre, PTFE fibre, polyamide fibre, polyester fibre	Monofilament, braided	Non-biodegradable sutures
Collagen, carbon fibre, polyester fibre	Braided	Artificial ligament
Polyamide fibre, polyethylene fibre, collagen, silk, polyester fibre, PTFE fibre	Woven, braided	Artificial tendon
Chitin	Nonwoven	Artificial skin

Table 9.4 Application of fibres in non-implantable materials

Fibre type	Fabric structure	Applications
Cotton, Lyocell, viscose	Nonwoven	Absorbent pad
Cotton, Lyocell, chitosan, viscose, silk, alginate fibre	Woven, nonwoven, knitted	Wound-contact layer
Viscose, plastic film, Lyocell	Woven, nonwoven	Base material
Cotton, polyamide fibre, elastomeric-fibre yarns, viscose	Woven, nonwoven, knitted	Simple elastic and non-elastic bandages
Cotton, Lyocell, viscose, elastomeric-fibre yarns	Woven, nonwoven, knitted	High-support bandages
Cotton, viscose, elastomeric-fibre yarns, Lyocell	Woven, knitted	Compression bandages
Cotton, Lyocell, viscose, chitosan, alginate fibre	Woven, nonwoven, knitted	Gauze dressing
Cotton, Lyocell, viscose, polyester fibre, glass fibre, polypropylene fibre	Woven, nonwoven, knitted	Plasters

9.3.3 Classification of Medical Fibres Based on Origin

Textile fibres are the structural elements, qualify to be processed into yarn, made from natural and synthetic material; and further to be knitted or woven by using specific interlacing methodologies or convertible into nonwoven fabrics such as felts or films [4]. On a molecular level, fibres are made of polymeric chains oriented in crystalline and amorphous segments, and extended crystalline structures known as fibrils. Textile fibres can be categorized on the bases of chemical structures, cross-sectional shape, length and width, surface contour, colour and their origins [16].

Nonwovens manufacturers have a wide range of polymers available, which are obtained from many sources, some are natural e.g. cotton, jute, hemp and some derived from natural sources (e.g. Viscose, Lyocell, cellulose acetate) and the rest are totally synthetic.

The polymer range includes absorbent cellulosic fibres, (e.g. Cotton, viscose and modified viscose) through to non-absorbent synthetics (e.g. Polyester, PTFE, carbon, aramid, acrylics, polyamide and polypropylene). More specialist polymers e.g. Alginate have also developed for application in medical field because of their unique characteristics such as water solubility, super absorbency, biodegradability and biocompatibility. Individual polymer type fibres also have different physical attributes, which can be used to produce different nonwoven properties. The fibres can have a finish applied, which can alter their very nature, i.e. an absorbent viscose fibre can be made hydrophobic while a hydrophobic polypropylene fibre can be made hydrophilic. In many conditions, the optimal output cannot be achieved by one fibre alone, hence many fibres may need to be blended to obtain optimum results.

9.3.3.1 Natural Fibres

Natural fibres are easily produced and extensively available due to their incredible molecular structure that provides a bioactive matrix which makes them biocompatible and biodegradable material. The nanostructure of natural fibre is not easily replicable due to complex and organized in motifs, as well as synthetic fibres do not have a multi-level structure as native materials. In contrast, specific material properties including tensile strength, hardness and modulus of elasticity are primarily constant for a natural fibre, but within synthetic fibre design they are more controllable. The molecular adaptation indigenous to natural fibre is seldom key to connection with blood and organ cells, cell receptors and proteins, which are presently being considered for a better understanding and advance medical textiles [17]. Man-made chemical fibres are fibrous structures constructed from both organic (both natural and synthetic polymers) and inorganic raw materials. Class of fibres reclaimed from natural sources is termed as “regenerated fibres”, while the fibres recovered from synthetic and inorganic raw materials are classified as “synthetic fibres”. In the following sections, the role of both natural and man-made fibres in the field of medical textiles will be reviewed in detail.

From the ancient time, natural fibres are used in medical applications. Although woody material is not likely for medical textile, with the record of most primitive documents, natural fibres are used as a prosthetic in the form of dentures in early civilizations [10]. Natural fibres are substances which primarily recovered from plants, animals and minerals as presented in Fig. 9.3. Plant fibres can be acquired from seeds such as cotton, coir, from leaves such as sisal and from stems such as jute, flax, ramie, etc. The animal-sourced fibres are largely composed of proteins, and can be segregated into silk, wool (that grow from the skin of sheep, Ovis Aries) and hair (animal fibres other than silk or sheep’s wool), e.g. from Vicuna (Lama vicugna), angora rabbit (Oryctolagus cuniculus), Mink (Mustela (Lutreola) vision), horse (Equus caballus),

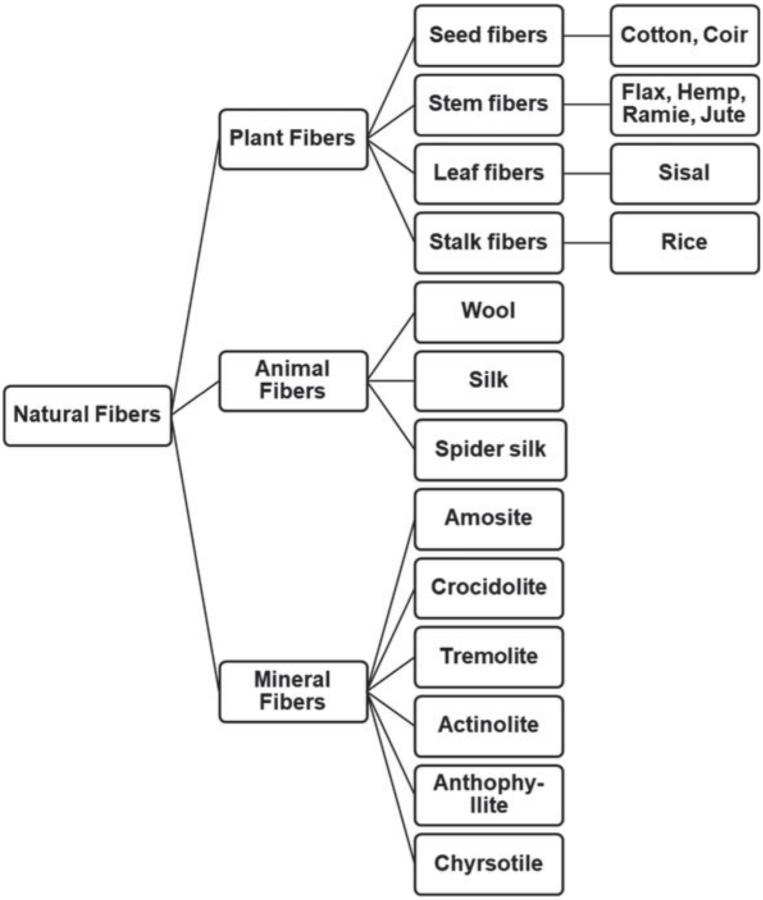

Fig. 9.3 Classification of Natural fibres

camel (e.g. Camelus bactrianus), cow (common ox, Bos Taurus), alpaca (Lama Pacos), goat (genus Capra, including angora goat, mohair, Capra hircus aegagrus and cashmere originally from the Asiatic goat, Capra hircus laniger), etc. [4]. Asbestos is only naturally occurring fibrous mineral used as fibres and exists in various forms such as amosite, crocidolite, actinolite, chrysotile, tremolite and anthophyllite.

Properties of Natural Fibres

As natural fibres acquired from natural sources such as plants, animals and minerals, so their properties greatly vary based on their origin or source. Cotton, flax and hemp all are cellulosic fibres. However, cotton exhibits twisted, convoluted ribbon-like structure, while flax or hemp shows bamboo-like morphology with polygonal cross-section. Similarly, wool fibres are crimped with scales on it, whereas silk demonstrates smooth surface round-edged prismatic like morphology. These morphologies define the physical appearance of the individual fibres irrespective of their chemical composition. Other physical properties orient from the internal crystalline structure of the individual fibres. Wool possesses α-helical proteins structure and silk bears β-pleated sheets of proteins. Thus, wool fibres offer better elasticity and extensibility than that of silk fibres. Cellulose-based fibres are excellent resistant to concentrated alkali and cold concentrated acids, but dissolve in hot concentrated acids. Protein-based fibres such as wool and silk are greatly damaged by alkali and concentrated acids. The Disulfide cysteine bond is determinant of a great number of chemical properties of wool fibres. Both cellulose and protein-based fibres are biodegradable, attacked by microbes and photodegradable. These fibres also exhibit very good moisture regain properties.

Suitability of Natural Fibres for Medical Applications

Cellulose-based fibres such as cotton are the most widely used natural fibres that play a significant role in wound dressing designs for decades. They are considered ideal candidates for hygiene and healthcare clothing owing to ideal properties that lie in the physiological comfort zone of human, and absorption properties. These fibres also have wide applications in non-implantable medical textiles. The proteinaceous natural fibres such as wool and silk are also distinctive in properties as cellulose. Some researchers have been trying to enhance the antibacterial and antifungal properties of natural fibres such as wool and silk. Usually silk fibre is also used for sutures but not more effective in other tissue sealing methods and may also be used in bone repair. Natural and synthetic fibres bearing antimicrobial properties or resist microbial adhesion qualifies better to become fibres for medical textiles. Thermal and tactile properties of healthcare textiles such as bed cloth and bedding, those are in direct contact with the patient's body, play a vital role in defining the microclimate around the human body. Both thermal and tactile properties of the fabric describe the comfort either by dissipating body heat to maintain thermal balance or transmitting water vapours coming from sweat and by imparting the feeling of softness and smoothness respectively.

Application of Natural Fibres in Medical Field

Both animal and vegetable origin products have been employed through ages because of their functional role to cure wounds, stop bleeding, pain relieving, absorb exuded substance and offer a defensive wall for the development of new tissues. In early civilization, different materials from the natural surroundings, such as wool-based materials, leaves and resin treated cloths with different substances together with honey and eggs are used. Some of these old remedies were probably more than alleviated treatments. For example, honey is used in wound treatment due to its antibacterial activity and being reconsidered as a successful antibiotic therapy. Modern studies imply that honey can endorse wound healing from monocytic cells through stimulation of inflammatory cytokines. Selection of dressing based on wound tissue colour, ulcer and infection. The body of operated patient is the biggest source of infection, hence, doctors and paramedical staff who are attending the patient seek protection from these infections by using protection garment such as surgical gowns. So, the design of these protective clothing should be performed under strict specifications. The fabric used should possess pore size that prevents the crossover of the pathogens. In a similar manner, the plain weave and circular knitted classical bandages should be built of highly twisted yarn to avoid the infiltration of fibres into the wound for easy and painless removal. As previously pointed out that thermal and tactile properties are significant for certain healthcare textiles that are made up of soft fabric with a smooth surface. Such fabrics have been developed using face to face velour weaving technique named as spacer fabric, which comprises of two distinct layers stitched together by a pile of yarns. These fabrics fulfil multiple objectives such as enhanced air permeability, better moisture management and much pronounced pressure relief. Spacer fabrics can be fabricated using either warp knitting or weft knitting techniques on a circular knitting machine with a double jersey or even on a double insertion rapier machine. Recently, intelligent garments have emerged as an innovative segment of textile sector, especially for medical and athletic textiles. Transcutaneous electrical nerve stimulation (TENS) therapy is implied in the remedy of various painful conditions. By introducing wearable TENS garments, a novel class of therapeutic textile for health care can be recognized. In such intelligent class of textiles, the distribution of pressure is imperative as these are in tight contact with the skin developed with elastic materials for effective treatment [18].

Plant/Vegetable Fibres

Vegetable fibres are usually based on the precise arrangements of cellulose, regularly with lignin. Basically, different parts of any plant are used in the development of vegetable fibre. In this regard, the seed, leaf and stem are the prime parts of the plant based upon the good work efficiency. The general sources of plant fibres are cotton, hemp, flax, jute, coir, ramie and sisal [16].

Seed Fibres (Cotton)

Cotton grows around the cotton plant's seeds (Gossypium), is the world's most used textile fibre because of its soft, cool and comfort characteristics. Cotton is mainly composed of cellulose made up of fine fibrillar structures (extended cellulose crystalline structures). These fibrils produce a well-organized system of capillaries that are continuous and very fine. Thus, the cotton fibre can be viewed as a microscopic physical sponge with a complex porous structure. This structure accounts for cotton's wick ability and unique absorbing capacity. In addition to excellent moisture absorbing, these fibres possess a good handle and a soft drape. Cotton fibres have been extensively employed in hygiene and healthcare products such as uniforms, pillow covers, sheets, bedding, surgical gowns and surgical hosiery. Additionally, these fibres have been used in non-implantable medical and surgical textiles gauze, wadding, tampons, simple bandages and absorbent swab [19].

Bast and Stem Fibres

Bast fibres are also known as the phloem fibres as they are collected from the phloem (inner bark of the plant stem). Flax (linen) is originated from the stem of Linum usitatissimum. It has a diameter ranging from 40 to 80 μm and exhibits a clockwise twist. The ultimate structure of the flax is polygonal in cross-section and small Lumina with thick walls. Microscopically, these fibres are roughly perpendicular to the long axis due to dark dislocations. This fibre is mostly used in clothing and household textiles. Another type of bast fibre, Ramie (Boehmeria Nivea) has a width ranging from 25 to 75 μm. In the microscopic examination, its walls appear as thick fibre and radial cracks might be present. Ramie is used in the formation of clothing articles, sacking and ropes as well. Jute (Corchorus capsularis) possesses a bundle like appearance and yellowish colour. Microscopically, it is polygonal but bony with medium-sized Lumina. It can be easily identified from flax by its anticlockwise twist. Jute is used in rugs and hardware cloth along with other products. Hemp (Cannabis sativa) can be easily distinguished from flax due to its wider lumen, fewer nodes and counter-clockwise twist. In cross-section view, hemp's Lumina is rounder and more flattened than jute. Hemp might be brownish in colour, and prepared products are ropes, bags and occasionally clothing [16, 20]. Traditionally, flax and hemp fibre threads had been used for the purpose of suturing. Hemp and linen fabrics have also been employed in hygiene products such as baby diapers.

Leaf Fibres
Leaf fibres, usually ascribed as hard fibres, are acquired by scraping away the non-fibrous material. This type of fibre is generally coarser than other fibres. One of its type, Sisal (Agave sisilana) is moderately easy to recognize due to its uneven lumen size, needle-like crystals, spiral and annular vessels. Sisal has also counter-clockwise twist. In the cross-section view, sisal seems to be like cut celery. It is used in the formation of twine, floor mats and carpets. Although abaca (Musa textiles) has many characteristics that help to identify it's difficult to identify on a slide mount. Apparently, it is waxy, darker than sisal and possesses a uniform diameter. Similarly, as in the sisal, abaca also exhibit counter-clockwise twist. The typical products of abaca include ropes, floor mats and cordage [16].

Animal Fibres

- **Wool**

Wool and other animal hair fibres are comprised of a sulphur-rich protein called Keratin, which exist as an alpha helix structure with molecular weights up to ~40 KDa. Wool-based dressing and bandages have been implemented to treat burn and chronic wounds such as ulcer due to their distinctive properties [21]. The use of oxidative enzymes functionalization of wool fibre enables the introduction of several novel properties.

- **Silk**

Silk also has been conventionally used as non-absorbable suture thread. Silk fibres are also employed to build artificial ligaments and tendons as well as absorbent pads. Silk fibre possesses superior biocompatibility and better mechanical properties. Silk fibrin can be electrospun to realize 2D and 3D matrices that offer great potential for tissue repair and regeneration [22]. The mechanical properties of the silk are more appropriate than polymeric gels, such as hyaluronan, collagen, alginate, which proved to be successful in 3D immobilization and maintaining the differentiated phenotype of chondrocytes. The phenotypical products collagen II and aggrecan were also detected around the cells that develop on the spider cocoon silk. A silk 3D textile could possibly be used in combination with a polymer gel, possibly alginate, in order to achieve certain biomechanical stability. While degradation is occurring, the silk textile becomes overgrown with real cartilage and will eventually recover the wound without any synthetic implants.

- **Spider Silk**

The hydrolysis products are frequently toxic in the case of synthetic polymers, but spider silk is a promising fibre for many applications because of exceptional mechanical properties. Spider silk has already proved its biocompatibility because it is completely made from protein. Harmless amino acid hydrolysis products make the silk a good candidate for the production of a bioresorbable textile scaffold [23].

Natural Fibres: Pros and Cons

The word textile has a different meaning not only concerned with the apparel. The need of products has augmented day by day owing to the development of industrial sector [24].Textile market is one of the fast-growing sectors of the world. Textile material is used in medical field, hygiene sector and applied health care. The variety of applications encountered in medical, hygiene and healthcare products are quite amazing, e.g. antibacterial, antimicrobial for wound treatment, simple bandages and biocompatible for body tissues. In the field of medical and textile industry, fibres, yarns, woven, knitted, nonwoven cover a series of application and show many end uses. In early time period, textile products are used for wound healing, plasters, simple and high-support bandages, etc.

Natural fibres are easily produced and readily available nowadays. Due to strong molecular structure, natural fibre affords a bioactive matrix for the design of more biocompatible and intelligent material. The nanostructure of protein and cellulose fibres is very complex and well-organized that cannot be effortlessly altered and duplicated. Natural fibres have great physical properties like tensile strength, elasticity [25].

Here are the advantages of natural fibres for medical textile:

- Natural fibres such as silk, wool, elastin, they are protein nature due to complex and unique structure, show a great **bacterial resistance**.
- Silk fibre is commonly used for suture.
- Natural fibres are **microbe adhesive**.
- The natural fibre makes surgical sutures, and these sutures have a great tensile strength, easy handling and firmness properties.
- Have a great bacterial filtration efficiency.
- Fibres exhibit resistant to body fluids.

- Flammability.
- Fibres are good for bandages, wound healing, gowns, gloves, plasters etc. in the medical field.
- Natural fibres show great properties like antifungal, antimicrobial, antibacterial against the bacteria.
- Natural fibre products stop to spread the germs.
- Good healing ability.
- Cost-effective.

9.3.3.2 Synthetic Fibres

Synthetic fibres, the man-made fibres are developed from a variety of raw materials, including petroleum and petroleum-based chemical resources. By using these materials, a variety of synthetic fibres are produced. The common types of synthetic fibres include saran, rayon, vinalon, modal, spandex and aramids. Wallace Carothers, an American researcher developed the very first synthetic fibre, nylon in 1930. Afterwards, the polyester, the second synthetic fibre came approximately ten years after the nylon production, and it is one the most pivotal development in the field of fibre industry. Each type of synthetic fibre has unique properties such as the degree of lustre and a sheen owns by the fibre depending upon its cross-sectional shape [26]. The synthetic fibres exist in the form of incessant filaments and staple, accounting for approximately partial of all fibre usage. Therefore, synthetic fibres have diverse applications in every field of textile and fibre technology. Likely, synthetic fibres are vastly applied in the field of medical textile and health care [27, 28].

With the fast growth of the society, resources are becoming scarce and it is ultimately increasing the importance of cultivating innovative technologies. So that, the next generation may able to engineer the biomaterials to encounter this need. Meanwhile, the new structural materials' development must be cost-efficient and rapid with the indulgence of environmentally sustainable and friendly behaviour. If the spinning process involved in the processing of synthetic fibres can be perfected and streamlined, artificial fibres may depict the potential usage for an extensive range of application, including ropes and cables, body armour and surgical suture [29, 30].

Generally, synthetic fibres have various characteristics, such as these are cheaper, more durable, stronger, easy to wash and maintain as compared to the natural fibres. Moreover, these are also waterproof and stain resistant [31]. Synthetic fibres are developed by following different techniques and technologies. Briefly, these include extrusion of fibre-forming substances named as spinning dope and this process of spinning dope is carried out with spinneret. The wet spinning method of fibre production involves various principles of its working such as coagulation, drawing stages and extrusion. All of these methods affect the behaviour and performance of the fibre. Very common and pivotal examples of wet spinning fibres are polybenzimidazole, polyvinyl chloride and spandex. While on the other hands, the dry spinning process of fibre formation involves the conversion of high vapour pressure of polymer solution into the solid fibre. The stress, mass transfer and heat transfer on the filament are the key variables in the dry spinning method. The spinning fibre acquires its final velocity in case of when the applied stress to spinning filament is no longer adequate to entice the fibre in a smaller diameter. The most potent dry spun fibres include acrylics, cellulose triacetate and cellulose acetate [32].

The classification of synthetic fibres varies according to the nature of their development. These include the major classes of synthetic fibres as man-made synthetic fibres and natural polymers regenerated synthetic fibres. Both classes of synthetic fibres encompass different types of synthetic fibres. These fibre types vary from each other by the means of their formation source [33]. The general properties of synthetic fibres are strength, colour, electrical conductivity, chemical composition, lustre, moisture absorption, elasticity and microscopic appearance. Depending upon all of these factors, the synthetic fibres hold a vast degree of discrimination among. Similarly, their application methods and resulting products also vary in relation to their general properties. Furthermore, the detailed description about the classification of the synthetic fibres is given in Fig. 9.4.

Physicochemical Properties of Synthetic Fibres

The synthetic fibres exhibit different physicochemical properties depending upon their method of development and the source of used materials. The chemical properties of different synthetic fibres discriminate among their types depending upon various corresponding factors. Moreover, the effects of different factors on synthetic fibres are designated in Table 9.5.

Biocompatibility of Synthetic Fibres

The biomaterial is any substance having a capacity to be replaced by any organ, tissue and functions of the body for a longer period except medication and food. These materials need to satisfy various requirements, such as biocompatibility, before they can be applied in vivo. Whereas, biocompatibility is defined as the ability of any biomaterial to execute the desired physiological functions regarding the medical therapy, devoid of exhibiting any unwanted systemic or local effects in the recipient. But, producing the most suitable advantageous effects on the tissues and cells and also optimizing the clinically applicable recital of that treatment [34, 35]. Electrospinning, an exciting methodology is fascinating in the field of medical textile and presenting the reasonable solution to the current challenges in the tissue engineering field. This procedure is used to make various fibrous scaffolds having an efficient extent of biodegradability and biocompatibility [36, 37]. The utmost need for the synthetic fibre's usage in the medical field demands its biocompatibility with the tissue scaffolds. Several other properties following their usage vary according to their application. Additionally, electrospun man-made fibres have allowed the specific tailoring of scaffold properties to carry out their anticipated properties [38]. The absorbance for these substances in the living tissue (in vivo) depends upon the chemical structure and degree of crystalline [39]. Meanwhile, among all other types of the man-made medical fibres, fibres with antimicrobial properties are the most potent because, antimicrobial fibres inhibit bacterial and fungi growth and ultimately can kill them. Therefore, following their high efficiency, the antimicrobial

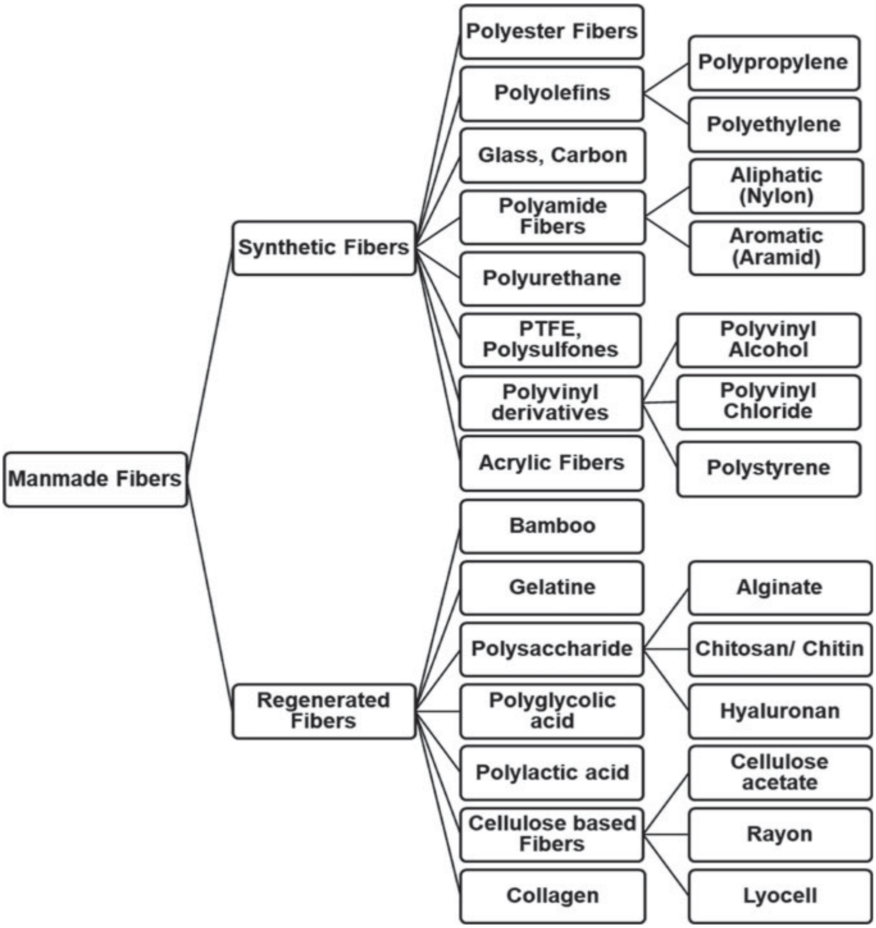

Fig. 9.4 Classification of man-made fibres

fibres have attained a basic position in the therapy, mainly in accelerating the wound healing along with the prevention of chronic wounds.

Application of Synthetic Fibres in Medical Field

Different types of synthetic fibres are being used in a variety of medical applications followed by their different properties. These properties include extensibility, strength, moisture and air permeability, wicking and flexibility. At present, the medical textiles account for a large market owing to the extensive need for them in the healthcare sectors and hygienic environment of hospitals. There has been a sharp upsurge in the use of the fibres for manufacturing the innumerable medical products [40]. The synthetic polymers have attained much high attraction in the medical application. Moreover, their diversified medical application is followed by the fact that multiple

Table 9.5 Physicochemical properties of different fibres

Fibre type	Effect of Acids	Effect of Alkalis	Effect of sunlight	Effect of organic solvents
Rayon	Disintegrate in cold concentrated and hot diluted acids	No effects by the weak alkalis but swells and loses the strength in concentrated alkalis	Generally resistant	Unaffected
Nylon 66	Resistant to weak acids only and undergoes decomposition by strong mineral acids	No or very little effects	No discolouration, but loses strength after long exposure	Unaffected but soluble in some phenol compounds
Acrylic	Resistant to acids (most acids)	Strong alkalis destroy at a boil, but resist to weak alkalis	Little or no effect	Unaffected
Polyester	Resistant to most of the mineral acids	Resist to cold alkalis	Some loss of strength	Soluble in some phenolic compounds
Acetate	Decomposition occurs by strong acids	Little effects from weak cold alkalis	Approximately similar to rayon	Soluble in chloroform, acetone and swollen by others
Triacetate	Decomposition occurs by strong acids	Not affected (up to pH 9.8)	Resistant but loses strength after long exposure	Soluble in chloroform, acetone and swollen by others
Olefin	Strong resistant	Very resistant	Very resistant	Soluble in chlorinated hydrocarbons above 160°
Glass	Resistant to acids (most acids)	Attacked by hot weak alkalis	None	Unaffected
Modacrylic	Resistant to acids (most acids)	Resistant to alkalis	Highly resistant	Soluble in warm acetate, otherwise remain unaffected

chemical and physical properties can be acquired based on their polymerization reactions, monomer units and production of co-polymers containing different components at adjustable concentrations. Besides these chemical and physical properties, there are some specific functional aspects of polymers which are being used. The semipermeable membranes of polymers or biopolymers such as cellulose are being used as a drug delivery system or haemodialysis. The collapsing or swelling of the pores of the membranes in response to the change in temperature, pH and any other stimuli causes the drug release in vivo [41, 42]. A vast area of medical textile application is the fabrication of orthopaedic support stuffs that protects and supports joints in different areas of the body. Back supports, shoulder supports, elbow supports, ankle supports, wrist supports and knee supports are some good examples of these applications. TENS therapy wearables are made up of elastic fabrics using spandex as a structural element [18].

Polyolefin Fibres

Polypropylene (PP), an Olefin fibre is composed of propylene and appears as rod like and smooth under microscope. Similar to all other previously described synthetic fibres, it also has staples and filaments in length. It evinces a translucent colour, dull, semi-dull or bright lustre, excellent strength (in accordance to the polymerization) and good elasticity with no moisture absorption. It melts on heat up to 330 °F and undergoes the progressive shrinkage from 140 °F to 212 °F. It burns slowly and owns an excellent electrical conductivity with a specific gravity of about 0.090–0.91. Polypropylene has an efficient resistance to most of the acids as well as alkalis. It loses its strength under sunlight exposure and even degrades in a longer period of sunlight exposure [43, 44]. PP fibres have been extensively used for hygiene, non-absorbable sutures, surgical gowns and protective clothing in medical field. In hygienic products, PP nonwoven layer has been induced as the distribution layer in diapers and spun-laced nonwoven sheet of PP and viscose rayon are used as wipes. PP hollow fibres are used to fabricate mechanical lungs. PP fibres also used in partially degradable implantable meshes with 50% polyglycolic acid, prostheses and plasters. Similarly, another synthetic fibre named as superld medical fibre is made by using the advanced manufacturing techniques. It is the ever first medical product containing highly softness and protective properties. Superld is a nonwoven fibre product produced by the polypropylene and polyester has the similar characteristics as owned by the polypropylene. Additionally, it has lower surface friction as compared to the other medical material and owns a more comfortable and easier wear [45].

Another Olefin fibre, polyethylene (PE), made up of ethylene, evinces rod like and smooth surface under microscope. It has staple and filaments in length, translucent colour with bright, dull or semi-dull lustre. It holds a fair to good strength depending upon the degree of polymerization, good elasticity and no moisture absorption. It burns slowly, too much sensitivity to heat and melts at 260 °F. It owns an excellent electrical conductivity and a specific gravity from 0.90–0.91 [43, 44]. PE has been used to make surgical covers and drapes. PE fibres are also employed as a top sheet of sanitary napkin and baby diapers and to sandwich multicomponent dressing. Artificial bones and ligaments can be fabricated using PE as mesh. PE fibres have been exploited as support in ion exchange fibres for drug delivery [45].

Polyvinyl Derivative

Polyvinyl alcohol (PVA) is a water-soluble polyhydroxy synthetic polymer that exhibits high strength, flexibility, emulsifying, excellent film-forming, water solubility and adhesive properties. PVA is chemical and biological resistant and offers high oxygen and aroma barrier properties. PVA spun into fibres by either dry spinning or wet spinning. Its water-soluble nature makes it a good raw material for many biomedical products including wound dressings and hydrogels. PVA can be easily crosslinked with other biopolymers that in results enhance its mechanical properties and reduce water solubility. PVA fibres incorporated with silver nanoparticles have proven as antibacterial hydrogel wound dressing [22]. Composite electrospun fibrous membranes of poly (ethylene oxide)/poly (vinyl pyrrolidone)-iodine complex and poly (vinyl pyrrolidone)-iodine complex has also found a prospective candidate for antimicrobial wound dressings [46].

Acrylic Fibres

Acrylic, a wool-like synthetic fibre have smooth and uniform surface area with irregular striations having a space within them. It is a chiefly staple fibre in nature and possesses off-white to white colour. Its elasticity is also very good and has fair strength with semi-dull, dull and bright lustre property. The specific gravity of acrylic is from 1.14 to 1.19 and possesses fair to good electrical conductivity. It burns with the yellow flame and tolerates the heat up to 450 °F. In case of acrylic, its properties are somewhat different from rayon fibre. It is damaged only by the action of strong and concentrated acids. Normally, it is not affected by the action of alkalis and has a very much higher resistance to the ultraviolet rays of light. Super absorbent fibres have been realized using crosslinked polymerized acrylic acid owing to their unique physical structure and dimension. Small diameter irregularly wavy or serrate fibres with longitudinal grooves impart very high surface area to the structure that affords very high moisture absorption properties even under pressure. Hence, acrylic fibres have been used in the production of cohesive dressing and bandages. Moreover, the acrylic is also used in hygiene and medical care because of highly absorbency behaviour [47].

Polyesters

Polyethylene terephthalate (PET), composed of ethylene glycol and dimethyl terephthalate, is the most versatile type of thermoplastic synthetic textile fibres. It appears as an even, rod like and smooth fibre in different cross-sectional shapes. It depicts a white colour and owns staple and filaments in length. It holds an excellent strength, dull or bright lustre and good elasticity which is higher than rayon or cotton fibre. It exhibits less than 1% of moisture absorption, burns gradually as well as bears the heat up to 400 °F. The electrical conductivity of this fibre involves accumulation of static charges with a specific gravity of 1.38. Furthermore, polyester has an efficient resistance to most of the acids and the alkalis along with the sunlight also. PET fibres have been used to prepare products such as gowns, masks, surgical cover, drapes, bedding, protective cloth, surgical hosiery, blankets and cover stock. Braided polyester filaments have been used to realize artificial tendons, arteries, heart valves, vascular prostheses, vascular grafts, surgical sutures and artificial ligaments [48]. Proflex ligament is made of polyethylene terephthalate polyester and consists of multiple braided tubes. A knitted PET vascular prosthesis has turned out as a standard vascular graft for substitution of arterial vessels of 6 mm and greater. PET fibrous structures are utilized as a mesh for dressing and plasters, while PET hollow fibres are used for artificial kidney. A two-stage modified polyester fibre exhibits a much high extent of the antimicrobial property. Thus, it is designated as for its use in various medical applications such as a surgical thread [49–51]. Two distinctive engineered polyester fibres with improved moisture wicking ability; one with four channel Dacron polyester fibre and other micro denier polyester blended with cotton, have been used to construct spacer fabrics for thermal and tactile comfort.

Poly-4-hydroxybutyrate (PHB) is another novel synthetic fibre of the polyester family with effective absorbable properties and implied in implantable medical applications. It is strong and flexible with an ability to degrade at least partially by the process of surface erosion in vivo. The PHB is clinically applied when there is requirement of in vivo surgical patching. A study testified that PHB has been demonstrated to be an effective support while preparing the antilogous cardiovascular tissue [52]. Polycaprolactone (PCL) has been yet another semi-crystalline polyester with a melting temperature of about 55–60 °C. PCL possess high solubility in organic solvents and low melting point and exhibits exceptional capability to be blended with a variety of polymers. PCL has been considered as a long-term controlled drug delivery application owing to its low degradation rate. In another report, an electrospun nonwoven membrane made up of PCL and poly (ethylene oxide) has been studied for controlled protein release [53].

Polyamides

Nylon, a polyamide fibre, has an even and a very smooth microscopic appearance. It is off-white in colour and carries staple and filaments in length. The nylon has an exceptional strength as high as 60,000–108,000 lb/square inch. The moisture absorption of nylon is 3.8% and its electrical conductivity is low as compared to other synthetic fibres. Nylon depicts high resistance to the heat as it melts slowly, and its peak of heat is 482 °F. Followed by its slow melting property, it does not undergo the combustion process. It has a very low specific gravity as 1.14. Nylon becomes weakened by the action of strong and concentrated acids and depicts much higher resistance to the alkalis. This fibre used to lose its strength when exposed to the sunlight rays for a longer period. The bright yam of this fibre is more resistant as compared to the dull yam. Polyamide fibres are employed to obtain surgical hosiery. Polyamide fibres have also been implemented to achieve surgical sutures, artificial ligaments, tendon and lumen, absorbent pads and simple bandages. Nylon also used as surgical dressings for wound management. One of such employment is the use of flexible nylon mesh coated with silicone as soft, porous and anti-adherent wound dressing [54].

Polyurethanes

Polyurethanes have been made into filaments with excellent elasticity. Polyurethane elastomers such as spandex have incorporated into surgical hosiery and elastic stockings for compression therapy. The processing of polyurethane filaments requires special equipment to guarantee a consistent and even compression effect. Polyurethane electrospun Nano fibrous membrane can be structured as a scaffold for cell growth and dual behaviour (hydrophilic and hydrophobic), wound dressing and bandages. Polyurethane urea elastomeric fibres implement for anterior cruciate ligament reconstruction. These fibres possess high abrasion, high strength and tissue compatibility [55].

Fluro, Sulphur and Silicon-Based Fibres

Fluro-bearing synthetic polymers such as polyvinylidene fluoride (PVDF) and polytetrafluoroethylene (PTFE) are chemical resistant, non-degradable, biocompatible and bioneutral in nature, have been widely employed for used in long-term medical implants and supports. Their greater surface tension allows easier cleaning of the surfaces. The multifilament yarn of medical grade PVDF has applied to realize medical sutures, ligaments, hernia meshes, vascular grafts and artificial cornea. Warp knitted fabrics of PVDF have been implemented to design hollow body prosthesis such as sutureless aortic valve prostheses, blood tight and elastic textile structures [56]. PTFE possesses high strength, hydrophobicity, chemical stability and one of the lowest coefficients of friction against any solid that qualifies PTFE for coating medical devices. PTFE fibrous structures have been used to realize vascular prostheses and grafts, cardiovascular implants, heart valves, artificial ligaments, filtration membranes, sutures, artificial ligament, artificial tendon and artificial lumen. Silicone has been implied for orthopaedic implants, artificial joints, artificial bones as well as non-adherent dressings [57]. Polyethersulfone hollow fibres and membranes have been employed in a bioreactor for haemodialysis and artificial kidney [58].

Inorganic Fibres

Inorganic fibres including glass and carbon fibres also made a pronounced impact in the field of medical applications. Glass fibres have been employed as structural materials for caps, surgical masks, artificial bones and joints. Optical fibres, mostly made of glass fibres, have also been implemented in medical diagnostic and sensing technologies [59]. Carbon fibres are biocompatible possessing remarkable strength. Carbon fibres have been exploited for the artificial replacement of injured/torn ligaments such as anterior cruciate ligament and tendons. Additionally, carbon fibres reinforced composites such as carbon fibres reinforced PEEK plastic have been successfully employed as orthopaedic implants, artificial joints and artificial bones [60]. Moreover, activated carbon fabric layer is commissioned for the wound management dressing to evade the odour.

Synthetic Fibres: Pros and Cons

The advantages of synthetic fibres are not limited to the specific words over the natural fibres. Briefly, these fibres possess multiple beneficial properties including higher biodegradability, biocompatibility, economic and bio-system friendly in nature. The production of synthetic fibres does not depend upon the animal and plant source largely as then can be produced by using different chemical and chemical like resources. These are cheap and are more durable as compared to natural fibres. These fibres readily pick up various dyes and offer consumer-friendly behaviour such as high absorbent, stretching, strain resistance and waterproofing properties. Moreover, the synthetic fibres are resistant to sunlight, oils, acids and alkalis. Besides, the most potent advantage of the synthetic fibres includes that mostly they do not undergo shrinking and last for much longer time as compared to the natural fibres. Also, these fibres dry quickly, and do not need extensive ironing. Moreover, several important types of synthetic fibres such as polyamide, polyethylene terephthalate, polypropylene and polyacrylonitrile are most extensively applied in the textile industry. These have surpassed the natural fibre production with almost market share of 54.4%. The corresponding advantages of these fibres are stiffness, tensile strength, relatively low cost and convenient processing ability [61, 62]. Despite the multiple advantages, there are also some disadvantages of these fibres. Generally, these include hydrophobicity, difficulties in finishing, tendency to pilling, insufficient washability and sometimes less wearing comfort. The most important disadvantage of these synthetic fibres is related to their low melting temperature. These fibres provide poor insulation, prone to heat damage and melt relatively easily. Also, they burn more rapidly as compared to the natural fibres. It is affirmed that synthetic fibres absorb a very minute moisture and become sticky in case of body sweats [61, 62]. Polyamide fibres are reported to retain more odour that cause microorganisms than natural fibres. Polyester and other synthetic fibres are also prone to the pathogenic microorganisms' growth.

9.3.3.3 Speciality and Regenerated Fibres

Biocompatibility of Regenerated/Specialty Fibres

Regenerated fibres are mostly reclaimed from the living sources. These fibrous structures exhibit distinct characteristics such as lack of cytotoxicity and allergenicity, biocompatibility, bioactivity (antibacterial activity), selectivity, absorbency, bioabsorbability and biodegradability to exactly withstand with the requirements of the medical field. However, these materials lack in mechanical properties such as strength, tenacity, elasticity and durability and biostability over long exposures. Hence, they have been usually implemented in products like sutures, wound dressing, drug delivery and scaffolds. Cellulose and its derivatives also demonstrate a greater extent of tissue biocompatibility. A genetically modified form of elastin has been used in repairing of cartilage tissue. By the molecular interactive properties, the carbohydrate-based wound dressings have received great interest in healing of chronic and burn wounds. Customarily, the use of carbohydrate-based wound dressing, including alginates, charcoal cloth, hydrogels and Chitosan provided properties such as ease in application and removal, absorbency, elasticity, occlusion and fluid balance. Collagen is a naturally occurring substance and its general applications are wound healing and tissue augmentation in dermatology. Their applications have been extended by fabricating reinforced or composite fibrous structures either with synthetic fibres or with themselves.

Application of Regenerated/Speciality Fibres

Wound healing happens in four continuous phases; homeostasis, inflammation, granulation tissue formation, and remodelling [63]. Textile-based structures have been considered good for wound healing process because of their higher surface area, larger porosity, and appreciable air and moisture permeability. Moreover, these structures bear strength, elasticity, extensibility and flexibility to reinforce with other healing substances. Carbohydrate-based wound dressings have recently made a significant impact owing to their molecular and mechanical interactive properties with chronic and burn wounds [63]. The conventionally used polysaccharide-based wound dressings include charcoal cloth, chitosan, xerogels, hydrogels and alginates possess the characteristics such as occlusion, elasticity, fluid balance, bacterial protection and ease of application and removal. For example, hydrogel-based wound dressings keep the wound surface moist and moderate the necrotic tissue build-ups that result in quick wound healing. Additionally, cellulose-based regenerated fibres such as viscose and Tencel exhibit very good moisture absorption properties with low adherent properties for heavy-exuding wounds. Collagen and gelatine have also emerged as potential candidates for interactive wound dressings. Selection of dressing for a particular wound is based on wound tissue colour, ulcer and infection [64].

Tissue engineering is another field of medical science where life encounters engineering and advance materials technologies. Three well-known approaches in tissue engineering are introduction of tissue-inducing substances, cell substitutes and placement of cells on/within matrices. The last approach has become widespread in which certain combinations of cells and scaffold materials have been developed as biological substrates to cure the dysfunction or loss of an organ. The scaffold is three-dimensional architectural support in which cells are implanted, permitted to grow and proliferate 3D to regenerate new tissues with appropriate structure and specific functions. Collagen, Chitosan, alginate, polylactic and polyglycolic acids are among the choice of materials to construct scaffolds made of nanofibres. Electrospun nanofibres made up of regenerated polymers found multiple applications in nanocomposites such as drug-delivery system, scaffolding and biomedical applications [65, 66].

Stent is considered as an important structural element to ease the intestinal obstruction and stenosis by imparting mechanical support for the restoration of lumen and smooth flow of body fluids [67, 68]. Biodegradable stents offer many advantages such as no need of further operation for their removal and prevention of serious long-term complications. Stents can be built with either weft knitting technology or braiding. The aliphatic polyesters, such as poly (lactic-co-glycolic acid) and polylactic acid are biodegradable polymers very commonly used for stents [68]. Polydioxanone, a novel biodegradable polymer also a competing candidate for stents because of minimal inflammatory response, biocompatibility, appropriate absorption rate, elasticity and good flexibility [69, 70].

Bamboo and Soybean Fibres

Bamboo fibres are intrinsically antibacterial fibres extracted from the bamboo plant. Bamboo fibre is a regenerated fibre that is softer and more absorbent than cotton, biologically degradable and antibacterial. The antibacterial capacity of bamboo fibres is attributed to the presence of an exceptional antibacterial and bacteriostatic bioagent called bamboo Kun. Because of its sterilization property by bacterial growth inhibition and bacteriostasis, this qualifies for the use of home furnishings and apparel and hygiene products [71]. The use of 100% bamboo fibres in surgical wears hinders bacterial growth. Soybean fibre is also a regenerated fibre with good physical properties that are good for human health [72]. Both bamboo and soybean fibres have been used for medical purposes and in baby clothing such as diapers. Multiaxial warp knitting fabrics using bamboo and soybean fibres have been reported as an alternative to classic medical bandages.

Polysaccharide Based Fibre

Alginate Fibres

Between 1912 and 1940, the Germans, Japanese and the British have secured many patents on the extrusion of alginates into insoluble fibres. Alginate is a natural hydrocolloid polysaccharide extracted from brown seaweed algae that gels to form fibres. Structurally, alginate is a copolymeric polyelectrolyte comprised of two building units: α-L-guluronic acid (G) and β-D-mannuronic acid (M). The counterions are generally calcium (Ca^{2+}) and sodium (Na^{+}). Alginate fibres are extruded through a simple wet spinning process in which extruded sodium alginate doped solution is coagulated through calcium chloride coagulation bath. In coagulation bath, sodium (Na^{+}) ion is exchanged with calcium (Ca^{2+}) ion that transforms the soluble strand of sodium alginate into insoluble fibres of calcium alginate. Calcium alginate fibres emerged from the bath are then washed, drawn and dried. Fibres made from alginate consisting of either a high proportion of G or M units impart them a specific set of properties. High M alginate usually gels more quickly associated with greater uptake of moisture and relative lower strength of the binding of Ca^{2+} ions, and hence weaker fibres. While, in high G alginate fibres are strong where Ca^{2+} ions are strongly bounded to structure that slower the gelation because of slower ion-exchange. Alginate wound dressings can be tailored with both high G or M contents as per wound management requirements. Nonwoven dressings made of alginate fibres offer multiple advantages over traditional dressing, especially in moist wound care [73]. Gelling properties of alginates fibres are both helpful in fibre extrusion and wound care management. Calcium alginate wound dressing in contact with body serum perform an ion-exchange with sodium and absorb moisture. This phenomenon results is swelling and hydrogel formation at the surface of wound blocking the lateral spread of infection. So, these gel-blocking, fluid handling, pain control, healing and hemostatic properties of alginate appreciate their use in wound treatment. Alginate primary dressings are not suitable for dry wounds but ideal for cavity wounds and medium to heavily exuding wounds. A typical alginate membrane, holds 90% free space, has also been exploited as scaffold [22, 74].

Chitin and Chitosan Fibres

Chitin (poly-1,4,2-acetamido-2-deoxy-b-D-glucose) is the second most abundant polymer in nature and exists extensively in the cell walls of fungi and crustacean shells. Chitin fibres have been proposed as a material that accelerate the wound healing process. Chitin is difficult to dissolve because of its peculiar physical and chemical nature. Various novel solvent systems have been designed that allow the chitin to be extruded into fibres, yet there is a need to make an impact. Chitin fibres proposed appropriate wound dressings applications [22].

Chitosan, the deacetylated form of chitin is also well-known for its antimicrobial, hemostatic and wound healing ability and polyelectrolyte in nature. Chitosan fibres are extruded from the acidic spinning solution of chitosan through spinnerets and precipitates into solid filament on passing through alkaline coagulation bath. Chitosan, one of the utmost polymers owns anti-tumour, non-toxicity, biocompatibility and biodegradability properties. It is most suitable for wound healing, especially burns due to its effective contribution to accelerating the tissue formation and homeostasis stimulation owing to release of Glucosamine [75]. Normally, the suture materials are coated with the silicon layer, but, the coating by using the Chitosan averts the inflammation as well as the scar formation along with an antimicrobial effect [76, 77]. Antimicrobial activity of Chitosan is linked to several factors; however, it is more effective in killing algae and fungus than bacteria. Its bacteriostatic activity is linked to its molecular weight [78]. Chitosan fibrous structures also have been implemented as tampons, scaffolds for tissue engineering and drug delivery. Additionally, modified Chitosan structures have also been exploited for their applications in biomedical industry. Carboxymethyl chitosan, in the form of hydrogel and nonwoven dressing, offers enhanced absorption characteristics as well as unique wound healing properties to cure chronic ulcerative wounds [79]. Cyanoethyl chitosan is another derivative of chitosan also have been employed as wound dressing owing to its excellent antibacterial properties [80].

Alchite Fibres

On gel formation, alginate wound dressings disintegrate and lose their strength. In multiple events, dressing cannot be detached in a single piece. This leads to the manufacturing of reinforced wound dressings that possess both gelling and non-gelling elements in the structure that results in a firm structure on soaking and facilitates the through and clean removal of the dressing. One of such examples is formation of alchite, the alginate chitosan, fibres. The unique combination of two polysaccharides leads to the development of a truly conjugate that offers distinctive mechanical and physical and properties different to those of individual chitosan and alginate fibres. Alchite fibre has rough; wool-like surface features, as opposed to rather smooth and plain surface characteristics of alginate fibres [81].

Hyaluronan Fibres

Hyaluronan or hyaluronic acid (HA) is another naturally occurring linear anionic polysaccharide comprised of repeating disaccharide units of N acetyl-D Glucosamine residues and D-glucuronic having a molecular weight ranging from 10^5 to 10^7 can form fibrous elements. The residues are both b-linked in the polymer, the glucosamine residue at positions 1 and 3, D-glucuronic acid being linked at carbon 1 and 4. It can be recovered from biological sources such as rooster comb, umbilical cord and bovine vitreous. It is a water-soluble polymer and provides viscous solutions. It is also an ideal candidate for wounding healing applications because it can interact with biomolecules, bacteriostat and scavenge free radicals at wound sites. Hyaluronan has also made an impact as a biomaterial scaffold in tissue engineering [82].

Cellulose-Based Fibres

Cellulose is the most abundant natural polymer made up of D-glucose and structural element of plant cells. It is insoluble in common solvents. Hence, the production of regenerated fibre of this naturally occurring polymer requires special solvents or modified approaches to realize the process. Rayon and Lyocell are the two medically used cellulose fibres, while cellulose acetate and carboxymethyl cellulose are derivative forms of cellulose.

Viscose Rayon Fibres

Rayon is a man-made synthetic fibre, possesses different physical properties. The microscopic appearance of rayon includes striations and speckled specks of pigment. While in length wise appearance, it involves staple and filaments. The visible colours of rayon are transparent and unless dulled by the pigments. Moreover, it has a fair level of strength, higher moisture absorption as compared to the cellulose. The rayon fibres use to swell in the water and burns much rapidly unless treated. The electrical activity of rayon fibre is fair enough that it enables the reduction of a specific charge following the precise mechanisms of fibre finishing. Rayon has a specific gravity as like cotton i.e. 1.52. The chemical properties of rayon are described as that it is damaged easily by the action of strong acids and resistant to the alkalis, but reduced in size, if the alkali is too much concentrated. This fabric undergoes the weakness under long exposure to the sunlight. It owns a better affinity towards dyes as compared to the cotton. These fibres are employed to acquire medical textile products such as caps, surgical gowns, masks, absorbent pads, wadding, plaster and simple bandages and wipes clothes. Knitted viscose dressings and gauzes may be used as the primary low adherent/anti-adherent dressings for the treatment of heavy-exuding wounds such as leg ulcers [83].

Lyocell Fibres

An innovative spinning cellulose fibre named as Lyocell was developed by Austria's Lenzing Company and Germany's Akzo Company. In this procedure, cellulose was dissolved into the viscous solvent, filtered and then spinning was done. Afterwards, the lyocell textile fibre was modified and named as hydrocele. The hydrocele may replace the alginate calcium, used to make the superior bandages to cure burn and wound. Lyocell fibres have been utilized for antimicrobial therapies. It has similar properties with the alginate fibre and provides a humid environment which efficiently promotes the recovery of wounds. Furthermore, hydrocele exhibits a higher water absorption characteristic as compared to the alginate fibre. It tends to reach 35 times of its own weight and also contributes to the formation of a contentious gel. Therefore, it is easy to apply as well as easy to change the bandage [84].

Cellulose Acetate Fibres

Another synthetic fibre named as acetate, is made up of the acetate ester of cellulose. The unique properties of acetate include its microscopic appearance as striations and lobed cross-sections with staple and filaments in length. It exhibits a transparent colour with dull, semi bright and bright lustre appearance. Its strength is less than rayon in wet form and possesses a moderate level of strength with not very high elasticity as similar to the rayon. Its heat bearing capacity is 275° F, 6% moisture absorption and undergoes the combustion too slowly. Its electrical conductivity is very good with a specific gravity of 1.32. The acetate fibre undergoes decomposition in response to the strong and concentrated acid exposure. Also, the strong alkalis and longer sunlight exposure damage this fibre and cause weakening effects. Cellulose acetate nonwoven fabrics have been successfully employed for the controlled release of vitamins and provide mesh for wound dressings. Cellulose acetate hollow fibres also have been exploited for the hemopurification and in the assembly of liver assist bioreactors [85].

Carboxymethyl Cellulose

Another useful material is carboxymethyl cellulose, the most abundant carbohydrates in nature, which can be produced chemically from cellulose. It has the advantage that it can be produced in a variety of molecular weights and can then be integrated with other materials such as alginate to produce synergistic behaviour in terms of physical properties. The Carboxymethyl cellulose is extensively applied in the medical field because of several corresponding properties; these include high water absorption, biocompatibility and biodegradability. Chiefly, it has been used in the forms of powder, films and gel [84]. The nonwoven made by CMC has been used as a wound dressing.

Polylactic Acid (PLA) and Polyglycolic Acid (PGA) Fibres

Polylactic acid (PLA) or Polyglycolic acid (PGA) is a linear aliphatic thermoplastic polyester derived from 100% annually renewable crops such as corn, wheat and sugar beet. Both PLA and PGA are used to fabricate bioabsorbable and biodegradable fibres. The PLA dope solution is prepared by dissolving in chloroform. PLA filaments are then spun by wet-jet-spinning techniques in which strands are precipitated in the non-solvent such as methanol that results in phase inversion. Phase inversion imparts porosity to the structure. Additionally, PLA fibres are also produced by wet spinning for certain biomedical applications. PLA most initial uses were limited to biomedical applications such as drug delivery systems and sutures due to availability and cost of manufacture. PLA fabrics can be used for the cultivation of different human organs. The process involves growing and culturing living cells, taken from human organs, on a textile scaffold, to the desired 2D and/or 3D shapes. Fibrous connective tissues replace the degrading implant during the degradation process. The key advantage is that no further surgery is needed to remove the products as they slowly degrade in the body without any side effects. Poly (lactide-co-glycolide) based electrospun Nano fibrous scaffolds have been incorporated with a hydrophilic antibiotic to control the release [86]. PLA provides absorbable surgical sutures scaffolds for bone tissue engineering such as regeneration and repair of bone and cartilage, skin grafts, implant materials, prosthetic devices. PGA is used as tubular resorb able nerve guides. PLGA is also a common choice in the manufacturing of many healthcare products such as micro and nanoparticles, grafts, implants, sutures, prosthetic devices.

Collagen Fibres
Collagen is a key protein in different tissues of animals and humans, fulfils the necessities of an imperative structural component in cooperation of non-implantable and implantable materials. The function of collagens in non-implantable materials are evident in interactive wound dressing, which has a mechanism-based mode of action either it is a native or electrospun form of collagen fibres to excite cell growth and boost soft tissue repair [87]. It has several levels of structure, which are attractive to study the role of collagen in biocompatible materials. Owing to its unique physiochemical, biological, mechanical properties and enzymatic degradability, collagen has been researched extensively for various biomedical applications. The use of collagen as a suture material dates back for a millennium, and one form of it, catgut, is still in wide use. Collagen fibrous structures have also been exploited to prepare tubular resorbable nerve guides and scaffold for tissue engineering [88].

Gelatin Fibres
Gelatin is achieved by thermal denaturing of collagen type I and II that is usually reclaimed from animal skin and bones using dilute acid. Chemically gelatin composed of 19 different amino acids bonded through peptide linkage. Gelatin also possesses good haemostatic properties. Gelatin hydrogel dressings are mostly used for burn wounds traumatic wounds, ulcerations and bedsores. Gelatin scaffolds have also been implemented for tissue engineering because it improves the growth and spreading of vessel cells [89].

Regenerated Fibres: Pros and Cons
Undoubtedly, Specialty regenerated fibres meet the demand of medical industry such as biocompatibility, bioactivity (antibacterial activity), selectivity, absorbency and bioabsorbability. These materials augment the skin tissues regeneration and reconstruction in comparison to conventional dressing materials. These materials can be incorporated into various textile structures with controlled architecture to ensemble with wound dressing and scaffold requirements. So, they can be easily applied to any place of the body because of their flexibility. On the other hand removal of hydrogel dressing is convenient and painless. For examples, alginate nonwoven wound dressings offer various advantages over traditional dressings because of its ability to contain exudate and gel-blocking phenomenon. Similarly, scaffold made up of these materials has been bioresorbable, consequently only tissue remains on the implant site. However, these materials pose some limitations related to their structural stability. For example, alginate dressing is difficult to remove as it is broken into various segments especially for cavity wounds. This shortcoming has been sorted out by developing reinforced/composite wound dressings.

Reinforced/Composite Fibrous Structures
It is pragmatic that an individual polymer cannot come up with all basic requirements for preparation of dressings for wound healing, hosts for drug delivery or

scaffolds for tissue engineering. In addition to this, all polymeric materials cannot be easily processed with established technologies, such as pure alginate solution cannot be effortlessly electrospun. These limitations led to the design of reinforced or composite fibrous structures. PVA and sodium alginate blended solutions can be conveniently electrospun in uniform nanofibres. On increasing the proportion of PVA, more uniform nanofibres have been realized. Here, PVA assists the electrospinning of the alginate [90]. Similarly, Chitosan-polyethylene glycol (PEG) blend improves the mechanical properties and biological characteristics of the membrane. In this instance, on increasing the proportion of PEG, the flexibility of the membrane enhances and results in lower bending length. PEG in the blend greatly influences the morphology and physical structure. PEG imparts the plasticization effect to Chitosan-based hydrogels same as imparted by glycerine [91]. In a study, collagen-alginate wound dressing found quite effective in the treatment of foot ulcer and heel pressure sore [92]. Collagen-chitosan blended membranes also exhibited superior wound management properties in comparison to commercial gauzes by promoting dermal and epidermal growth [93]. PLA-Chitosan composites have been structured into nonwoven fibrous mats for wound dressing, and filament yarn as surgical suture. It has been reported that PLA-chitosan hybrids inhibit the bacterial growth and foster wound healing process [94]. Quaternized chitosan along with PVA has also electrospun into Nano fibrous mats with antibacterial properties [95]. Gelatin has also composed with Tencel and polycaprolactam to realize wound dressing and fibrous composite scaffolds respectively [96]. Preparation of ibuprofen-loaded poly (lactide-co-glycolide)/poly (ethylene glycol)-g-Chitosan electrospun membranes have been reported for simultaneous wound management and on-site drug delivery [97].

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Chapter 10
Fibers for Other Technical Textiles Applications

Zuhaib Ahmad, Muhammad Salman Naeem, Abdul Jabbar, and Muhammad Irfan

Abstract During the past few years, the use of technical textiles has grown rapidly. Natural, synthetic, and high-performance fibers are being used in many technical textile applications. Some of which are explained in detail, while others are in brief in this book. This chapter reviews the application and use of natural, synthetic, and high-performance fibers for Indutech, Hometech, Clothtech, Buildtech, Packtech, and Oekotech. As the strength of natural fibers is not so good, the use of synthetic and high-performance fibers is increasing in industrial and technical products. One of the major applications of technical textiles is in the filtration media. The performance of a specific filter is based on the selection of fiber, textile material, and the way they have been assembled. The properties of fluid for which the filter has to be designed must be considered carefully as well. Human beings have been using regular clothing to protect themselves from a very hot and cold environment. The workers in some occupations (like military, police, firefighting, and healthcare) are exposed to different hazards, so they are required to wear protecting textile clothing, which is discussed further in the chapter. For centuries, textiles are being used for construction materials whether it is for insulation or reinforcement of any other application. However, the use of advanced construction material specifically textile fibers has increased extensively these days. It is important to have appropriate knowledge about textile fibers in the light of current climate change and other global challenges, as textiles in any form (fiber, yarn, or fabric) provide excellent thermal and mechanical properties with low weight. Today the people around the world have become more educated with higher living standards. Therefore, the use of high technology products, which offer enhanced performance, durability, hygienic conditions, and

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Table 10.1 Classifications of Technical Textiles

1. Protech	2. Sportech	3. Mobiltech	4. Geotech
5. Agrotech	6. Medtech	7. Indutech	8. Hometech
9. Clothtech	10. Buildtech	11. Packtech	12. Oekotech

Table 10.2 Industrial applications of remaining classifications of Technical Textiles

#	Type	Industry	Application
(a)	Indutech	Electronics, Filtration, and other industrial materials	Textile-reinforced rubber products, filtration, lifting, composites, cleaning, electronic components, pulling, others
(b)	Hometech	Furnishing, floor coverings, and habitat	Carpet and furniture components, filtration, cleaning, tarpaulins, coverings, etc
(c)	Clothtech	Shoes and clothing	Shoe components, sewn products, structure, and insulation
(d)	Buildtech	Building and construction	Construction materials and building components, protection, screen, reinforcement
(e)	Packtech	Packaging	Block and disposable packaging, ties, and others
(f)	Oekotech	Environmental protection or shield	Transverse field, products obtained from previous sectors

aesthetic, has become the need of the day. The demand for eco-friendly and biodegradable packaging is growing now as they have a great impact on human health and the environment. The use of natural fibers for environmental protection is not new. While the use of synthetic and high-performance fibers for environmental protection is a revolutionary change in the current century. One of its uses is in protecting the crops and soil artificially by weather changes to increase productivity. The new and advanced developments for environmental protection keep on increasing across the world in the coming years. In this chapter, an overview of such types of textiles; fibers being used; and their applications, advantages, and drawbacks have been provided briefly.

There are 12 classifications of technical textiles according to the market sector [1], which are given in Table 10.1. The first six classes have been discussed comprehensively in the previous chapters of this book. The applications of fibers in the remaining classes of technical textiles will be discussed in this chapter. The industrial applications of these technical textile classes are given in Table 10.2.

10.1 Natural Fibers

The natural fibers are categorized into three main categories which are animal, vegetable, and mineral fibers. Natural and other fibers differ from each other due to their structures. Cotton, silk, wool, and other natural fibers have uneven and non-homogeneous surfaces [2]. The applications of natural fibers in the technical textiles are discussed in the following sections.

10.2 Applications

(a) **Indutech**

Industrial textiles or Indutech can be defined as specially designed materials and structures that are used in the manufacturing and processing of different industries. Different applications of industrial textiles can be summarized as battery separators, transmission/conveyor belts, safety belts, high-temperature bearing belts, sound-absorbing materials, filters (air filter, oil filter, cigarette filters, fuel filter), nuclear biological protection masks, ropes, tire cords, automobile usage, and textiles in civil engineering.

Natural fibers can be used as a constituent fiber in composites, where the direction of placement of fibers can affect the properties of the composites. They can also be converted into sheets to manufacture materials such as fabric, paper, and felt.

Natural fibers are also used for high-tech applications, for example, composites used for automobiles. Composites containing natural fibers have improved thermal insulation, low density, and decreased skin irritation as compared to those containing glass fibers. Natural fibers are also biodegraded by bacteria once they are no longer used [3]. The most commonly used natural fibers for industrial and technical applications are cotton and some coarser vegetable fibers, including jute, sisal, and flax. Usually, heavy canvas type fabrics, ropes, and twines have been produced by them. The importance of natural fibers is increasing in fiber-reinforced composites, packaging, automotive, aerospace, and other high-performance textile applications.

(b) **Hometech**

The importance of Hometech has been recognized and the role of technical textiles in this field is increasing at a substantial pace. It comprises household textiles, upholstered furniture industry (like wadding and fiberfill applications in sleeping bags, cushions, and bedding.). Both natural and synthetic fibers are also used in household textile materials, unlike other kinds of high-performance textiles. These fibers come from the same sources used for common fabrics such as wool (for carpets), cotton (for towels), and polyester (for curtains).

Solar textiles which are inspired by the biological models (such as polar bear fur) are used for the semi-transparent thermal insulation of the buildings. The dark absorber sheet behind the transparent front sheet warms up when the sun shines through the front sheet. The heat is converted through the brick walls in the house by an absorber. A coated flexible spacer textile containing smooth foils on both sides is responsible for insulation. The top side functions according to lotus effect for self-cleaning purposes and the bottom part in the form of a black pigmented coating functions to absorb sunlight and converts it into heat [1, 4].

Insulating textiles, being flexible and lightweight, are becoming an important part of wall constructions. In combination with suitable fabric finishes, novel systems like aerogel impregnated textiles, that can act as insulating core, can be easily installed [5]. Instead of falling under the category of "household" or "home", such textiles (solar and wall covers) are included under the category of "construction building" textiles. Hence, it is clear that hundreds of square meters in a house could be covered by textiles.

The textiles are also being used to get fire resistant and flame retardant properties and the commercial examples of fire resistant and flame retardant textiles comprise of the Ultem® 9011 Polyimide, the Visil® rayon fibers, Pyrovatex®CP cotton, the Basofil® melamine, and the Tes-firESD® fabrics which are both flame retardant as well as antistatic [1].

(c) **Clothtech**

The role of clothing is very important in human life, as it protects them from their surrounding environment. In some fields, workers are open to some hazards like chemical substances (e.g., acids or flammable materials), hot liquids splash, chilled air, heavy rain, high heat (e.g., flash fires, steam, electric arc), bullets or knives, nuclear elements biological materials (e.g., bacteria, viruses), radiological threatening agents, and/or extreme cold air/water [6–8]. Employees (e.g., healthcare staff, military personnel, police officers, and firefighters) have to wear textile-based personal protective clothing (PPC), in order to get protection from such hazardous working environments [9, 10]. After the selection of suitable fibers (e.g., natural, synthetic, or a blend of different fibers), various spinning techniques (e.g., ring spinning or rotor spinning) are used to spin them into different types of yarns [11].

Keeping in view the properties (tenacity, temperature, elasticity, limiting oxygen index (LOI), combustion, and moisture regain (MR)), two natural fibers are most commonly used for PPC. These are cotton and wool. In recent times, some other natural fibers such as flax, silk have been introduced for use in the manufacturing of PPC. It is noted that these naturally occurring fibers are quite expensive. Therefore, a less costly regenerated natural cellulosic fiber known as "viscose" is used nowadays for the manufacturing of PPC. A few, regenerated natural inorganic fibers (e.g., eco-friendly glass and ceramic fibers) have also been used for the manufacturing of PPC along with natural or regenerated organic fibers (e.g., cotton, flax, silk, and wool) [12–14].

(d) **Builtech**

It is not known exactly when the textiles were introduced to be used as a construction material. But, nowadays textile materials are being used in the construction of public spaces (temporary or permanent) on a large scale. The building or construction applications, mostly include textile-reinforced concrete (TRC), architectural textiles, insulation, and house wraps [1]. For non-structural applications such as filters, bags, fishnet, broom, and multipurpose rope, natural fibers have been cultivated and used extensively in rural developing countries. These fibers have also been used for housing applications such as roof material and wall insulations. The composites of natural fibers may be a combination of either natural fibers and a synthetic resin or natural fibers and bio-resin (biodegradable resin). Another idea of a natural fiber composite beam was an I-shaped beam developed using vacuum-assisted resin transfer molding (VARTM) or resin vacuum infusion process method. The woven jute fabric known as burlap and soybean oil-based resin system has been used to develop this composite beam structure [15]. The woven mat of sisal fibers or cashew nut shell liquid (CNSL) [16] and recycled paper reinforced with a foam core is one of the natural fiber composites for making roof materials [17]. Recycled paper composites have also been used to develop a natural fiber composites panel appropriate for housing construction materials and furniture [18]. Jute mats reinforced composites have been used for the trenchless restoration of underground drain pipes and water pipes in the areas of structural rehabilitation [19]. According to the previously mentioned studies, it has been highlighted that natural materials can be used successfully to develop a load-bearing material for roofs, beams, and panels. It has been observed that for many infrastructure applications, the natural fibers are being used as compared to the synthetic fibers [20]. The heat flow through building components is reduced by the insulation, which is a thermal barrier layer and it improves the building's energy efficiency. Mostly, the insulation materials are either in the form of fibers or foam. As shown in Fig. 10.1, fibrous insulation materials may be fiberized as inorganic fiber–fiber products or organic fiber-based products [1].

As compared to organic fibers, inorganic fibers have been developed to give higher performance. Precisely, inorganic fibers show improved product lifetime and better thermal stability [21]. The use of organic fibers is limited in the insulation field due to their lower resistance to high temperatures and environmental extremes [22].

(e) **Packtech**

In the current age, people are shifting their focus toward the use of smart packing materials. Packtech is among the most essential areas of technical textiles. Packing materials should possess strong mechanical and physical resistance to thermal processes [23]. Natural and synthetic fibers are equally being used in packaging. Such fibers originate from the same sources used in common fabrics such as jute (e.g., for food sacks) and polyamide (e.g., for packaging bags). Bast fibers are lingo cellulosic plant fibers. These have been used for years in the manufacturing of packaging and bagging materials from hemp, flax, and ramie [1].

The bio-based packaging materials are being preferred for packaging. In this group of materials, the special interest has been given to fibrous cellulose for packaging.

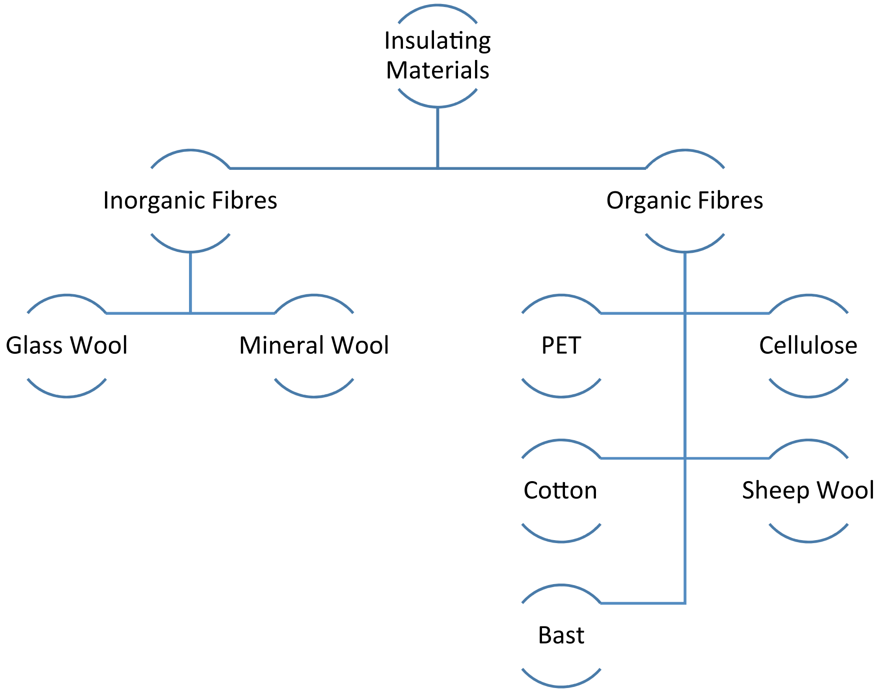

Fig. 10.1 Insulation material types [1]

The foams based on cellulose nanomaterial are being studied for packaging uses in substitution to polystyrene-based foams. The polymer which is being produced from fossil fuel is replaced by a renewable material, i.e., the webs of cellulose nanomaterials. In packaging, it is advantageous due to a reduction in weight and being environmentally friendly [24].

(f) **Oekotech**

Oekotech is a class of technical textiles that involves preservation/protection of the environment through the use of technical textiles. Textiles are used in different ways in environment protection and conservation like providing alternatives to polythene bags, use of different woven or knitted fabrics in air filtration like simple filtration, pressure filtration, activated carbon-coated cloth, air filtration in vehicles, manufacturing plants, personal protective air filtration masks, advanced water treatment through different membranes by using different technical textiles and different innovative technologies for recycling. As we know that textiles are deteriorating our planet. Not only natural fibers, but also synthetic fibers are equally participating their role in increasing population. Natural fibers, like cotton and jute, are although biodegradable, but their growth demands an enormous amount of water together with a huge amount of pesticides. An estimate tells us that the production of 1 kg of textiles requires nearly 200 L of water and around 50% of the total pesticides for growing cotton [25, 26].

Advantages and Drawbacks

Natural fibers show excellent specific tensile strength and stiffness, in some cases better than glass fibers but slightly similar to synthetic fibers. In addition, they also show other advantages like production flexibility, enhanced energy recovery, production simplicity, and carbon dioxide sequestration. They are also eco-friendly and are obtained from renewable natural resources. The industrial sector requires materials that are durable as well as biodegradable at the end of service life [27]. An effective contrast of mechanical properties should be done in terms of their specific mechanical properties. According to it, certain tensile strengths of some of the natural fibers, such as flax, hemp, kenaf, and Caraua are quite similar to that of the E-glass fibers. Hence, natural fiber-based products are usually used in technical textiles and as reinforcements in composite products used in transportation sectors [28].

In case of home textile applications, each textile has a different flammability grade regarding fire resistance and flame retardation, depending on the type of fiber being used. Considering the example of wool, it does not burn easily as compared to synthetic fabrics like polyester which catch fire easily. To improve the performance and safety features of the products such as carpets and curtains, flame retarding agents are used [29].

Any type of natural fiber is said to be ecologically sustainable when it is biodegradable and requires less industrial processing to be produced. Therefore, it is required to study the use of other natural organic fibers (such as jute, ramie, and hemp) except for cotton, flax, viscose, silk, and wool for personal protective clothing and other technical applications [30].

The composition of packaging materials has made recycling costlier as compared with the disposal in the landfill. These facts have led to the development of biodegradable plastics for sustainable packaging applications from renewable raw materials like cellulose or starch. Waste management of such plastics is done by composting or anaerobic digestion. Materials have been manufactured from a combination of paper fibers (virgin or recovered wood fibers) and textile dust, fibers (waste from mechanical recycling of textiles) in the case of innovative packaging [1].

In building materials, the natural fiber composites are gaining attention again due to the need for more environmentally friendly materials. Presently, the growing use of natural fiber composites is due to environmental and low-cost benefits rather than their strength capabilities [20].

There are some limitations of natural fibers as they have a comparatively high weight, low resistance to water, fungal, and microbial attacks as well as weak flame retardancy. The use of synthetic products in structural and infrastructure applications has gained attention, due to the main drawback of natural fiber composites which is the enormous variation in the properties of the natural fibers, their treatments, and manufacturing optimization. These problems need to be considered in order to produce and develop better structural elements that can be used for both infrastructure and structural applications [20].

The textile sector is among one of the few sectors which are increasing at a rapid pace because of the increase in population. Although this expansion is providing jobs and boosting the economy of many countries, but at the same time creating serious environmental hazards in the form of land pollution, air pollution, and water pollution. Every year a huge burden of used textile waste is increasing. More than 83.5 million tons of textile waste are produced currently which is expected to increase up to 62% by 2030. The major portion of which goes to landfills which have been banned in some European countries. Therefore the concept of circular economy, sustainability, organic cotton, and eco-friendly textile products gained more attention.

10.3 Synthetic Fibers

The properties of naturally occurring animal and vegetable fibers have been improved by extensive research, resulting in synthetic fibers. Side by side with natural fibers, the use of synthetic materials like polypropylene, polyamides, polyethylene, polylactide, and others is increasing because of versatility, enhanced strength, resistance to different chemicals, hydrophobicity, abrasion resistance along with a prolonged life cycle [2].

Applications

(a) **Indutech**

As different industries require special characteristics so different kinds of polymeric materials are used for different applications depending upon end usage. Nowadays the filtration industry is not only technically sophisticated but it is a huge market with annual sales around $100 billion [1]. The filtration and other related separation techniques and equipment are divided into two sectors. One of which is a commercial and domestic sector with water, coffee, and suction cleaner filters and the other one is transport system with coolants and engine filters for the intake of fuel and air. The required characteristics in fabrics used for filtration are tensile strength, chemical resistance, permeability, and abrasion resistance [31]. However, it depends upon the chemical and thermal conditions of gas and liquid that needs to be filtered out. The most widely used synthetic material in the filter media is polyester (around 70%). The strong base causes degradation of polyester fibers. The polyamide fibers also lose strength and degrade in the presence of a strong base, although they provide good abrasion resistance. Polypropylene is most widely used in filtration media because of its inert nature in the presence of chemicals; however, oxidizing agents cause negative effects on the stability of polypropylene. It is suitable for melt-blown and spun-bond non-wovens. Yet, it has a low melting point as compared to others [32]. Polytetrafluoroethylene (PTFE) which is an expensive fiber has the potential to be used in the presence of different chemicals [1].

The invention of conveyor belts and transmission belts brought about a revolution in industrial manufacturing. The usage of synthetic fibers in this segment is more as compared to natural fibers as they possess poor strength. The key features required in ropes are flexibility, durability, strength, handle, and shock resistance. Synthetic fibers are used both in staple fiber or filament form. Polyamides have elasticity, high level of extension, flexibility, high abrasive resistance, and high level of energy absorption capability. However, in wet form, they have poor abrasion resistance, loss of strength (10–20%), and kink formation. Polyester fibers are strong, abrasion-resistant in wet conditions, have less elongation than nylon but better fatigue properties than nylon. Polypropylene is softer in handling and cheaper than polyester and nylon. But it is 30% weaker in strength than polyester and nylon and also degrades in the sunshine.

(b) **Hometech**

Globally household textiles, whether derived from natural, synthetic, or special fibers account for nearly 7% share of the total market of technical textiles [33]. Home textiles have improved the status of houses through peculiar designs. The usage of home textiles is increasing day by day as with better living standards people want well-furnished homes with improved aesthetic and functional home textiles. The key to their success depends on their way of fabrication along with the coating.

The Hometech products can be categorized as towels which are used for drying, wipes for cleaning and other purposes, woven or non-woven blinds for windows and doors, bed linen and comforters for sleeping, blinds for hanging at the doors and windows, carpets for increasing aesthetics of house, tents, and nets for giving protection from sun or rain also protecting from insects (mosquito nets), home wear clothing for personal clothing, napkin for cooking, filtration cloth for home vacuum cleaners, ventilation systems, and air conditioners, non-woven wipes for personal hygiene, non-woven make up wipes, table covers, and a number of other applications [1].

Natural fibers, synthetic fibers, and high-performance fibers along with different construction techniques are being used in home textiles. Different synthetic fibers find different applications in different fields like polyester fibers are widely used for curtains along with the filling of pillows, comforters, bolsters, soft toys, furniture back, sleeping bags in the form of small fibers, ball fibers or as a lining material. For carpet backing cloth, polyester, polypropylene, or their blends are used as polyester provides strength, mildew, and abrasive resistance [34]. Polypropylene is also employed for filtration cloth as well. Viscose and polyester also find their application in non-woven wipes. However, acrylic (PAN) is mostly used for sweaters, rugs, socks, and water bath mats as it has a wool-like structure and wrinkle resistant but at the same time, it melts when burning.

In a study, woven polyester fabrics have been used to manufacture sound-absorbing curtains to achieve high performance of textile structures. Three to five types of yarns with different linear mass densities and different weaving patterns were used to produce fabrics of increasing area density, cutoff frequency, and specific airflow resistance [35].

(c) **Clothtech**

Clothtech is a class of technical textiles that consists of special materials and constructions primarily used in apparel and shoes. Most of these components are hidden as they are used as an interlining or lining purpose. The most promising products that come under Clothtech can be classified as sewing thread, labels, interlining, zip fasteners, umbrella cloth, shoelaces, and Velcro. Sewing thread accounts for nearly 60% of total technical textile consumption under the category of Clothtech followed by labels 19% and interlinings around 8%.

Sewing thread can broadly be divided into two categories like industrial sewing thread (used for joining different elements together) and surgical sutures. Surgical sutures (biodegradable or non-biodegradable) and industrial sewing threads have different requirements from manufacturing and usage point of view. Technical sewing threads have been established to meet particular applications like sewing of leather items, filtration items, heat resistant sewing threads, for sewing apparel, tents, sleeping bags, and in automotive industries [36]. Sew ability of sewing thread can be influenced through different parameters like extensibility in sewing thread, the balance of twist among different plies, and thread friction (due to the interaction of sewing thread with machine components and fabric) [37]. Mostly spun threads are made by using different materials like polyester, cotton, cotton-polyester blends, Kevlar, Nomex, wool, viscose and acrylic fibers. These kinds of threads have a fuzzy surface. In core-spun yarn, polyester is mostly used in the core while different materials are used as a sheeth. However, for elastic yarns, different elastomers are used in the core which give a higher extension for sewing thread [1].

Lining and interlining materials in garments are used to support and enhance the aesthetics of the outer shell in garments. Careful selection of lining material is very important, particularly inside coats and in lightweight materials as low-quality interlining can spoil the aesthetics and performance of high-quality apparel. Differential shrinkage, bubble formation on outer shell fabric and losing the grip of interlining with outer fabric are the most common problems faced with the application of interlinings. Interlining can be woven or non-woven which can be stitched or heat set with the fabric depending upon the end usage. The raw material used in linings is a lustrous fabric with a good hand feel like cotton or silk. While in interlining polyester, cotton, nylon, viscose, and wool are preferred choices [38].

The textiles are used in shoes as the upper part, lower part, and laces. The upper part of shoes comprises 40% cost of sports shoes. The inside layer of the upper part of the shoes is equipped with special characteristics like porosity and comfort. The most commonly used synthetic materials for shoe linings are vinyl and tricot [39]. Vinyl and tricot are mostly used because they are inexpensive materials and are impermeable. Textile materials are incorporated into the footwear in different ways like non-woven absorbent material (Cambrella), a combination of hydrophobic and hydrophilic layers, different types of air meshes, special membranes (Gore-Tex) for selective transport of moisture and air, breathable foam or backing material [39]. Shoelaces are mostly constructed in woven or braided form with different kinds of materials like cotton, polyester, or nylon.

Sometimes, synthetic fibers or filaments are directly used in the non-woven processes such as chemical bonding, mechanical bonding, and electrospinning to yield non-woven fabrics [40]. The moisture regain (MR) and glass transition temperature is dependent upon the polymer composition of the fibers. It is noteworthy that the LOI values of the fibers produced artificially (regenerated natural fiber, viscose, and synthetic fiber polyester, etc.) could be improved by doping the phosphorous-based flame retardant (FR) chemicals within their polymer compositions. The improvement of LOI could help to convert an unsuitable and non-fire retardant fiber (viscose and polyester) for PPC into a suitable and fire retardant fiber (Fire Retardant viscose and Fire Retardant polyester) [1].

(d) **Buildtech**

Food, cloth, and shelter are among the basic needs of human beings. Humans are in a continuous struggle to improve the construction of living through the use of different styles of architecture for better protection against rain, wind, cold, hot, and for personal protection. Since the living conditions vary in the different parts of the world, so the architecture style also changes like open houses in a hot climate while closed structures are observed in cold regions of the world. However, in recent years mega structures like huge bridges, big dams, long tunnels, multi-story buildings and shopping malls, heavy-duty roads, etc. have been evolved which require special characteristics not only to increase the life of these structures but also to reduce cost, improve protection of human beings from breakdown, and other hazards like fire and earthquake. In general, while selecting material for Buildtech following things must be kept in mind like mechanical stability (fatigue limit, creep, tensile strength, foldability, and tenacity), barrier or resistance functions (UV and IR radiation, excess amount of water, insulation from hot and cold weather, humidity, and corrosive gases), light transmission or translucency, burning behavior, sound damping, and ease of cleaning.

Different lightweight structures and membranes find different applications like permanent placement as cover in a sports stadium, marriage halls, temporary, or portable construction. However, in both cases strength, cost-effectiveness, and durability are prime factors. Mostly the membranes are made of PTFE-covered glass fibers and polyvinyl chloride coated polyester fibers, while in new structures high strength polyester with different coatings is also being used. Polyethylene terephthalate (PET) is used to give superior strength, tenacity, and high bending recovery values. It does not absorb moisture, which is the main reason for its chemical inertness along with its low cost makes it an ideal candidate to be used in Buildtech.

Because of climate change, environment is getting severe day by day. In hot areas, every year temperature is increasing while in cold climate temperature is getting cold. So, builders are trying difficult strategies in order to cope with the issue of environmental extremities as a significant amount of energy that is spent on cooling and warming buildings can be avoided. The insulating material can be used in different forms like roll, loose-fill, and rigid form or reflective foams the choice of insulation material depends on the application, cost as well as desired characteristics in material [41]. Different materials are available for thermal insulation like cotton, cellulose, glass fiber, polystyrene, foamed rubber, polyethylene, polyisocyanurate, polyurethane, and other polymers.

The geopolymers have some additional benefits over conventional cement but due to their cross-linked structures, geopolymers are found brittle and can form crack easily as compared with ordinary cement [42, 43]. Therefore, more and more research is undergoing in order to improve the fracture characteristics of a geopolymer through different means like the incorporation of different types of fibers (basalt fibers, polyvinyl chloride, polypropylene, and steel fibers). These fibers found to be effective in improving mechanical properties, especially increasing fracture energy.

(e) **Packtech**

From heavyweight woven structure of lightweight materials, continuous sheets of plastic, flexible intermediate bulk containers (FIBC), biodegradable materials, wrapping materials for textiles and food materials (tea bags, packing of food containers for temporary and prolonged time), perforated structures combined with knitted and non-woven materials come under the category of Packtech. Almost all Packtech except jute bags come under the category of flexible packing materials. A smart or active packing system can be explained as a packing system in which the shelf life of the product is enhanced through the combined action of packing material, environment, and the product. Different factors contribute toward enhancing the shelf life of a product like releasing or retaining moisture transportation, removal of oxygen, controlling of temperature, etc [1].

Leno bags for packing, preserving, and carrying vegetables and fruits are preferred choice which is made from polyamides or polypropylene. These bags are suitable to be placed in cold storage, with good aesthetic and mechanical properties. Further, these are able to be recycled, reused, and are easy to handle. However, jute bags are used for storing grain and rice and in the cement industry as well. These bags are environment-friendly, but they are coarser and loose strength in getting moisture.

The luggage materials are categorized as soft luggage and hard luggage material. Molded plastics that come under hard luggage are mostly used for travel bags. Outside shell requires strength, abrasion resistance, nice color, and flexibility that is why polyester, nylon, polypropylene, leather, and other high-performance fibers are used. However soft luggage comprises woven fabrics made from nylon, polyester, and Cordura®. Ballistic nylon as compared with other materials is very lightweight, easy to clean, and durable. However, polyester is the most liked soft material because of its lower price. Currently, soft luggage is getting popular because of its flexibility, lightweight, and easy to handle characteristics. It includes athletic backpacks, briefcase, wallet, military backpacks, and handbags.

(f) **Oekotech**

The synthetic fibers are not biodegradable and are a severe threat to the environment in the form of solid waste management. This situation has been further aggravated because of excessive use of transportation and discharge of polluted air without purification into the environment [44]. Particulate matter at the base of particle size is categorized as PM2.5 (i.e., particle size less than 2.5 μm) and PM10 (i.e., particle size less than 10 μm). The earlier one is more dangerous and hazardous because it can go up to the lungs because of small particle size [45]. There are two different types of filters which are available in the market:

1. The first type of air filter comprises fibrous materials. These kinds of filters trap air particles through adhesion and thick structure. For effective working on these types of filters more thickness is required. The main problem associated with these kinds of filters is their thick structure.
2. The second type of filter comprises a porous membrane filter which is developed by creating porosity in the surface of the material. The presence of pores on the surface of materials helps in providing clean air to its wearer [46].

Different techniques and materials are being applied to the elimination of different pollutants from the polluted air. Polyamide filters are capable of removing PM2.5 at high temperatures [47]. Yang developed Nanoporous polyethylene membrane masks for indoor and outdoor applications.

Filters can be classified on the basis of materials used for their construction like linen, wool, carbon black having high porosity, glass fibers, rayons, and metal powders. Different types of new polymeric materials are also being employed individually or in combination with different materials through different mechanisms like chemical coagulation methods, biological breakdown methods, physical or chemical adsorption, and different types of membrane filtration. However, some of the famous textile materials find special applications like glass fiber for concentrated hot acids and chemical solutions, orlon for acids (including chromic acid) and petrochemicals, vinyon for acids, alkalis, solvents and petroleum products, dynel for acids, alkalis, solvents and petrochemicals, polypropylene for acids, alkalis and solvents (except for aromatics and chlorinated hydrocarbons), polyethylene for acids and alkalis, PTFE for all chemicals, PVC for acids and alkalis, polyester for acids, organic solvents and oxidizing agents and nylon for acids, petrochemicals, organic solvents and alkaline suspensions [48].

10.4 Advantages and Drawbacks

Due to the availability of the latest biodegradable polymers such as polylactic acid (PLA) obtained from corn, the market demand for natural fibers is also changing. To keep a balance between price, performance, quality, ecological regulations, and supply of natural fibers, a number of high-performance fabric and composite manufacturers are developing novel facilities to use alternative fibers. The durability of synthetic fibers is good and the tensile properties of E-glass are better than natural fibers [1].

Conventional filter fabrics were made from cotton fiber whose efficiency increases by absorbing moisture as they swell, but they work best at a lower temperature, in the absence of acidic conditions, having a shorter life cycle. Synthetic fibers as compared with natural fibers are more durable and possess superior mechanical, chemical, and physical characteristics. The use of synthetic fiber cloth as filtration media offers several advantages like higher filtrate purity, reducing the weight of fabric filter, higher mechanical strength, and chemical resistance combined with easy washing and drying. Similarly, the synthetic fibers have their own advantages, in use for home textiles, that are difficult to achieve in natural fibers like high strength, abrasive resistance, hydrophobicity, durability, and many others [34]. The PET fibers have a major disadvantage when used in Buildtech, they lose 50% of their strength on exposure to UV radiation.

Most of the materials used today for packaging are non-degradable, and they greatly affect human health and the environment. Hence, the demand for finding advanced and eco-friendly packaging materials is growing which may have greater mechanical, physical, and barrier properties [1].

Currently, the packing industry is dependent on petrochemical-based materials which are a serious threat to the environment and are also burdened on the economy [49]. Now the trend is shifting toward the use of conductive, antibacterial, and biodegradable plastic materials in order to avoid problems of microbial interference, improving quality, and conserve the environment [50].

Every year a huge burden of used textile waste is increasing, which is affecting our environment. To reduce textile waste around 7% of polyester production is being made from recycled polyester worldwide [51]. Most of the recycled nylon is used in the carpet industry and mostly nylon-6,6 is mechanically recycled from pre-consumer fibers [52].

10.5 High-Performance Fibers

As compared to conventional fibers the high-performance fibers have been developed with improved physical properties and have enhanced performance such as heat resistance (high decomposition temperature and high melting point). These super fibers have strength more than 20 g/den (2.2 GPa) and modulus more than 500 g/den (55 GPa) [2].

10.6 Applications

(a) **Indutech**

Technical textile fibers containing superior mechanical, thermal, and chemical characteristics have offered a unique generation of composite materials. The increasing pollution mainly air and water pollution and its effects on humans and filtration processes have become significant. Filtration has presented surface modification for better health and a cleaner environment [53–57]. Air and water filters are of great significance and high-performance textile structures are mostly used for the filtration process of these fluids. Technical textile engineering gives 3D networks of fibers for effective filtration. The surfaces of these textile fibers capture particles. Consequently, fiber surface structures are critical to filtration efficiency. The efficiency of a technical fiber depends upon the boundary between the fiber surface and the matrix in the composite filter media [58]. Glass fibers and Teflon are used for high-temperature filtration. Glass fibers have a strong particle capturing capacity, whereas ceramic fibers are suitable for hot glass filtration [32].

Because of the poor strength of natural fibers, the usage of high-performance fibers (fiberglass, Kevlar fiber, and aramid fiber) for conveyor belts and transmission belts is increasing. Kevlar has a high modulus, strength to weight ratio greater than other synthetic fibers, less extension as compared with polyester and nylon low corrosion, and creep.

(b) **Hometech**

A high-tech category of household textiles also contains luminous embroidered fabrics. As compared to traditional embroidered ones, they show both a decorative and a luminous effect after absorbing visible light, storing energy, and releasing it as a light in the dark for more than 10 h. Generally, luminous fabrics are manufactured by weaving, knitting, or embroidering the rare-earth luminous fibers such as europium ions and activated strontium aluminate phosphors onto fabrics.

Most modern high-performance household textiles are those protecting from electromagnetic radiation. Such a quality can be achieved by using electro-conductive covers. They can generate and transport free charges. E-glass/polypropylene commingled yarn is an example of conductive polymer coated yarn manufactured by the P-D Fiberglass Group (Germany) [59].

Chlorofibers (CLF) is a flame retardant fiber, which gives real protection against the danger of fire. It has hydrophobic nature, dimensionally stable, and acoustic insulation properties as well. Whether used pure or in blends, the CLF fibers retain all its characteristics and can be made into all sorts of fabrics. The non-flammable nature of the fiber makes it ideal for wall coverings, hangings, curtains, and upholstered furniture [60].

(c) **Clothtech**

The textile materials are being used in footwear in different ways, one of which is odor-absorbing textiles like carbon-coated soles [39]. Besides the use of natural and synthetic fibers in shoelaces, the use of velcro, loop closures, and specialty yarns like Kevlar is also common in mountaineering products in order to impart durability and strength. In special dress like bikers clothing, high-density panels of foam in shoulders, hips, back, elbows and knees are used which are made by Kevlar, leather, and other polymeric materials.

In multifilament threads, different materials can be used depending upon end applications like polyester, nylon, coated E-glass, Nomex, polyether ketone, spectra, and different types of metalized threads are also being used [1]. The use of conductive sewing yarns is also gaining importance in Clothtech [36].

(d) **Builtech**

Humans are already in use of different materials like the incorporation of straw in mud to increase the strength of reinforcement. Now the trend of adding different types of fibers (natural fibers, synthetic fibers, metal fibers, high-performance fibers, special fibers for special properties like carbon fibers for enhanced thermal properties), high strength and high modulus fibers like aramid, glass fiber, polyester fiber, PBO for advanced mechanical properties and other stuff for special characteristics come under this category.

The membrane structures used for architectural structures are of two types:

1. A coated or laminated fabric consisting of a textile substrate (nonwoven or woven) with a coating of protective polymer.
2. A single-layer polymeric films or foils.

Normally, the fabric layer of the coated fabric is woven from polyester, aramid, or yarns [62]. Fiberglass or glass wool, a material made from very fine glass fibers is one of the most used insulation materials [1]. The most commonly used fiber types of textile-reinforced composites (TRCs) are the alkali resistant (AR) glass fibers and carbon fibers. Alkali resistant glass fibers and carbon fibers are not easily corroded and also have high strengths [63]. Alkali resistant glass and carbon fibers are used as filament yarns or rovings as shown in Fig. 10.2. These materials show low material strain under tensile load which is necessary for reinforced concrete structures. Lately, in the area of TRCs, basalt fibers have gained attention due to their low cost and property of being environmental-friendly [64]. TRC has been

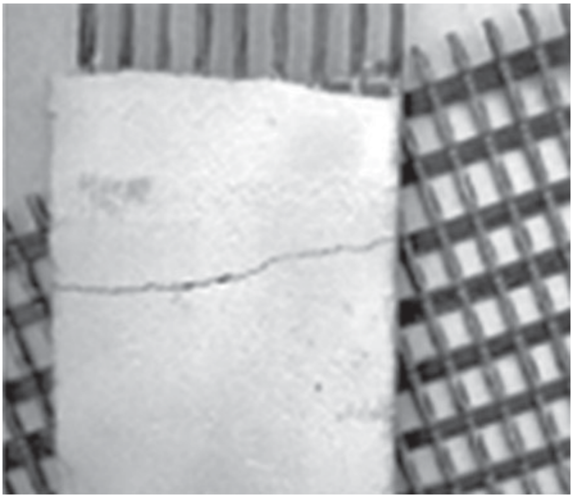

Fig. 10.2 Carbon fiber textile structure and its incorporation into the concrete. *Source* Images from [61]

used in many applications such as facades, noise barriers, roofs, balconies, tanks, furniture, bridges, and pipes.

The geopolymers are not able to resist elevated temperatures because of their inadequate and non-consistent properties, especially if the building gets fire [65–67]. It is therefore required that in new constructions such types of fibers or filler particles should be incorporated that can enhance the mechanical properties of cement even at higher temperatures [68]. Different materials are being used by different researchers and carbon materials appear to be a potential candidate for reinforcing geopolymers because of their enhanced thermal and mechanical properties. In this regard different carbon materials like carbon nanofibers, carbon nanotubes, graphene, etc. are being incorporated in geopolymer for enhanced mechanical, high energy for fracture, and thermal resistance at elevated temperatures [69, 70].

(e) **Packtech**

In molded plastic bags polycarbonate, carbon fiber, and composites are being used as they provide high strength and abrasion resistance. High modulus polypropylene is used in luggage, cases, and other fields where safety, toughness, and further high-performance factors are crucial [60].

(f) **Oekotech**

Different methods like physical, biological, and chemical methods are being employed to treat industrial waste effluents from different hazardous materials like synthetic dyes, chemicals, acids, oil components, and more specifically heavy metals. The type of material and method employed for waste treatment depends on the kind and size of particulate matter in wastewater. In this regard, cellulose acetate and different kinds of aramid hollow fibers are used in fiber-based filtration media [71]. Out of different technologies, carbon-based air filters seem to be more effective not only because of less thickness, but also due to enhanced inter particulate surface area and higher porosity. They used to filter air particles mostly through physical adsorption [72]. Around 20% of the total production of activated carbon is utilized in air filtration in different industries [73].

The textile materials selected for water filtration must possess some special characteristics like high biological resistance, hydrolytic nature, resistance against a wide range of pH, temperature and different types of chemicals used in manufacturing sectors. Aramids, fluorocarbon, polysulfone, phenylene sulfide, polyimide, PEEK (Victrex) are among famous examples used in liquid filtration under different types of environmental conditions [74].

10.7 Advantages and Drawbacks

The tensile properties of high-performance fibers (Kevlar, Carbon) are better than natural and synthetic fibers. Liquid crystal polymers are aromatic polyesters with high mechanical properties because of high crystallinity. They are also inert along with high thermal stability. Aramid fibers were developed in order to increase chemical stability. Due to the stability of aromatic rings, they have higher thermal resistance and tensile strength as compared with aliphatic polyamides, so they can be preferably used in Buildtech. The most common issue related to fiberglass insulation in buildings is its tendency to break. The glass fibers can cause lung damage when inhaled [1].

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