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Introductory Chapter: Textile Manufacturing Processes

Faheem Uddin

1. Introduction

Textile fibers provided an integral component in modern society and physical structure known for human comfort and sustainability. Man is a friend of fashion in nature. The desire for better garment and apparel resulted in the development of textile fiber production and textile manufacturing process.

Primarily the natural textile fibers meet the requirements for human consumption in terms of the comfort and aesthetic trends. Cotton, wool, and silk were the important natural fibers for human clothing articles, where cotton for its outstanding properties and versatile utilization was known as the King Cotton.

Cotton is an important natural fiber produced in Asian and American continent since the last around 5000 years in the countries including the USA, India, China, Turkey, Pakistan, Brazil, etc. [1]. The advancement of fiber manufacturing introduced several man-made fibers for conventional textile products; however, cotton is to date a leading textile fiber in home textiles and clothing articles. The chemistry of cotton fiber is the principal source of interesting and useful properties required in finished textile products [2]. Strength, softness, absorbency, dyeing and printing properties, comfort, air permeability, etc. are the important properties of cotton to remain an important textile fiber in the market. By 2018 cotton fiber was significant with a market share of 39.47% as raw material in textile products.

Cotton fiber grown with increased environment-friendly properties is called organic cotton. It is grown without using any synthetic chemicals or pesticides, fertilizers, etc. Organic cotton is produced through crop with the processing stages in an ecological environment. Turkey, the USA, and India are the main countries producing organic cotton.

The other important natural fibers used in conventional textile products are wool and silk. Wool fiber is known for its warmer properties and used mainly in winter wear mainly. Wool-based textile items are projected to witness a CAGR of 3.7%, in terms of volume, from 2019 to 2025. Importantly, wool fiber is renewable and recyclable, which supports its demand in this industry [3].

Silk fiber is known for its unmatched softness and low linear density. Relative to cotton and wool, natural silk is not produced in significant quantity. It is indicated to have the highest revenue growth rate of 4.67% from 2019 to 2025.

A recent study of textile fiber market share by the IHS Markit has shown the synthetic fibers consumed highest (mainly represented by polyester and nylon fibers) followed by cotton, cellulosics, and wool fibers (**Figure 1**) [4]. China is the major manufacturer of synthetic fibers. Excluding polyolefin fibers, China produces around 66% of synthetic fibers in 2015.

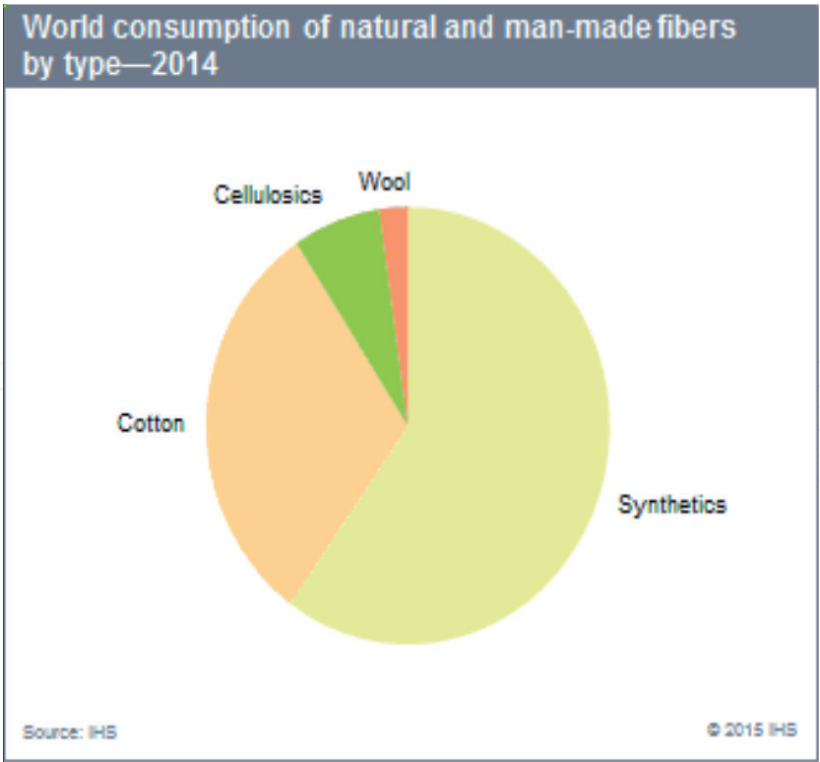


Figure 1.
Natural and man-made fibers consumed in the global textile market (IHS Markit [4]).

The textile manufacturing processes are largely required by the fashion segment in the global textile market. The large amount of textile products, demanded by fashion, accounted for more than 65% of textile product market. Fashion market is followed by technical textiles and household products. Grand View Research indicated fashion, technical textiles, and household as the top three sectors by application for the global textile market (**Figure 2**) [3].

Compound annual growth rate of 4.25% is expected over the years 2018–2025 in the global textile market. This market was estimated at USD 925.3 billion in 2018. The growth is significantly expected in the apparel sector. China and India will remain the leading countries to experience this growth. Increasing urban population with rising disposable income is the main source of higher growth in apparel consumption.

The textile manufacturing processes in the global textile industry are producing the textile yarn, fiber, fabric, and finished products including apparels. The global textile industry associated with the apparel and non-apparel products is expected

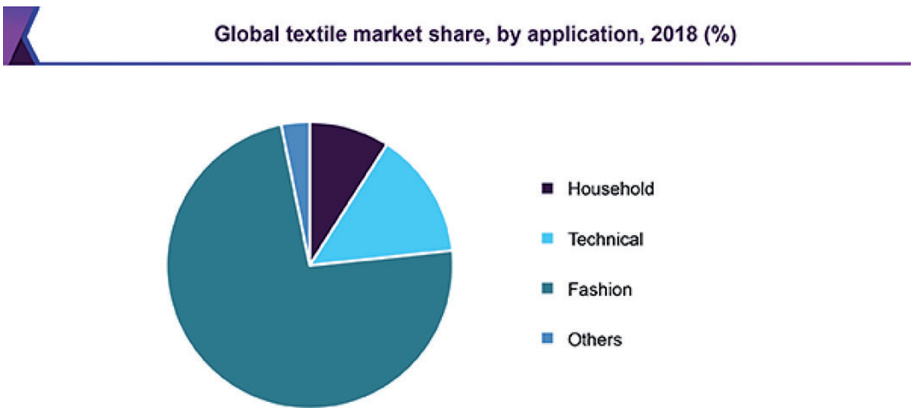


Figure 2.
Important textile fiber product types in the market in terms of application (Grand View Research) [3].

to exceed USD 1000 billion in the next couple of years [5]. The textile industry market is mainly represented by countries China, the USA, India, and the European Union. China is indicated as the country with leading textile manufacturing facility representing around one-fourth of the global textile industry.

An important aspect that has received increasing concern in textiles is the release of environmental hazard from fiber and fabric process industries. Most of the processes performed in textile manufacturing release significant toxic and hazard waste to river water, soil and air. Particularly fiber and yarn manufacturing, chemical finishing, pre-treatment processes, dyeing, printing, coating, and drying operations are releasing toxic gases, carcinogenic materials, harmful vapor and lint, and effluent discharge. Consequently, standards and regulations are evolved to limit or eliminate the environmental depreciation.

2. Textile manufacturing process

Today the textile industry encompasses a significant number and variety of processes that are adding value in fiber. These processes may range over the yarn making through the garment stitching, fabric embossing, and composite production. However, considering the textile fiber as the basic building unit of any textile product, the textile manufacturing may clearly be identified as the conventional and technical textiles.

The conventional textile manufacturing process has a long history of converting the natural fiber into useful products including fabric, home textiles, and apparel and more recently into a technical textile through the utilization of special finishing effects (**Figure 3**).

The synthetic and semisynthetic fiber manufacturing is diversified with the utilization of monomer, chemical agent, precursor, catalyst, and a variety of auxiliary chemicals resulting in the formation of fiber or yarn. However, such man-made

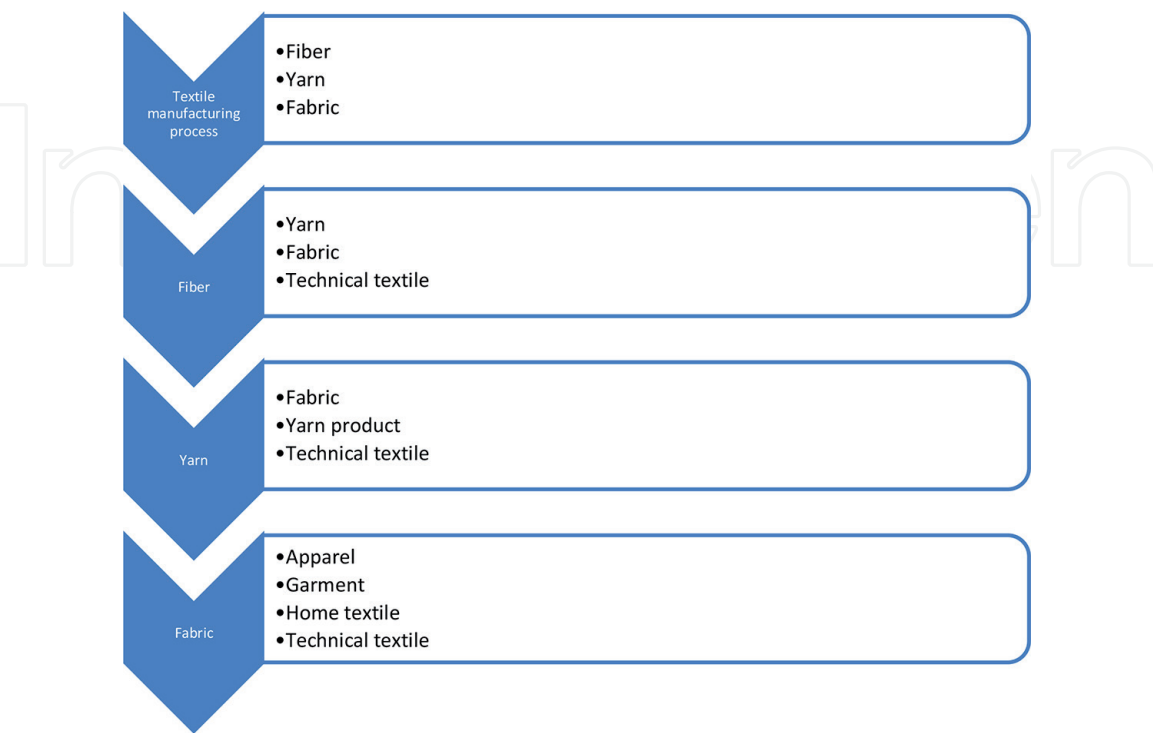


Figure 3.
Textile manufacturing process from fiber to fabric.

fibers are perceived as a separate specialized subject and beyond the scope of this book. Therefore, the man-made fiber manufacturing is not discussed.

The innovation in textile manufacturing introduced variety in raw materials and manufacturing processes. Therefore, process control to ensure product quality is desired. Monitoring and controlling of process parameters may introduce reduction in waste, costs, and environmental impact [6].

All the processing stages in textile manufacturing from fiber production to finished fabric are experiencing enhancement in process control and evaluation. It includes textile fiber production and processing through blow room, carding, drawing, and combing; and fabric production including knitted, woven, nonwoven, and subsequent coloration and finishing and apparel manufacturing.

The global textile industry, in yarn and fabric production, has strong presence and experiencing growth. In 2016, the yarn and fabric market was valued at USD 748.1 billion, where the fabric product was more in consumption and contributed 83.7% and the yarn product was at 16.3%. The market consumption is forecasted for growth at CAGR of 5.1% between 2016 and 2021, reaching to a market value of USD 961.0 billion in 2021 [7].

Apparel production is another important area in textile manufacturing around the textile industry chain. Probably the apparel is what an individual wear for the purpose of body coverage, beautification, or comfort. Apparel and garment terms are used interchangeably. However, the two terms may be differentiated as apparel is an outerwear clothing and garment is any piece of clothing.

The study of apparel manufacturing market includes all the clothing articles except leather, footwear, knitted product, and technical, household, and made-up items. The worldwide apparel manufacturing market was valued at USD 785.0 billion in 2016 and estimated to reach the level of USD 992 billion in 2021. The market enhancement is forecasted to move from 2016 to 2021 at CAGR of 4.8%.

3. Types of textile manufacturing process

3.1 Yarn manufacturing

Traditionally, yarn manufacturing comprises a series of processes involved in converting the fiber into yarn. It was rooted in natural fibers obtained from natural plant or animal sources. Natural fibers are produced with natural impurities that were removed from the yarn in subsequent pretreatment processes.

Possibly, cotton is the fiber that has rooted the yarn manufacturing from fiber bale opening, followed by the series of continuous operations of blending, mixing, cleaning, carding, drawing, roving, and spinning. Yarn manufacturing using cotton fibers through a sequence of processing stages may be shown by process flow diagram (**Figure 4**) [8]. All these operations are mechanical and do not require chemical application.

Each processing stage in yarn manufacturing utilized the machine of specialized nature and provided quality effects in yarn production.

The advancement in fiber processing and machine technology for yarn manufacturing is continuous. The manual picking of cotton fiber is now replaced with machine picking. However, conventional systems of blending, carding, drawing, roving, and spinning are indicated important in the future [9].

Yarn diameter, hairiness, linear density, permeability, strength properties, etc. depend upon the end-use requirement of fabric to be produced for woven or knitted end products (e.g., apparel or industrial fabrics), sewing thread, or cordage.

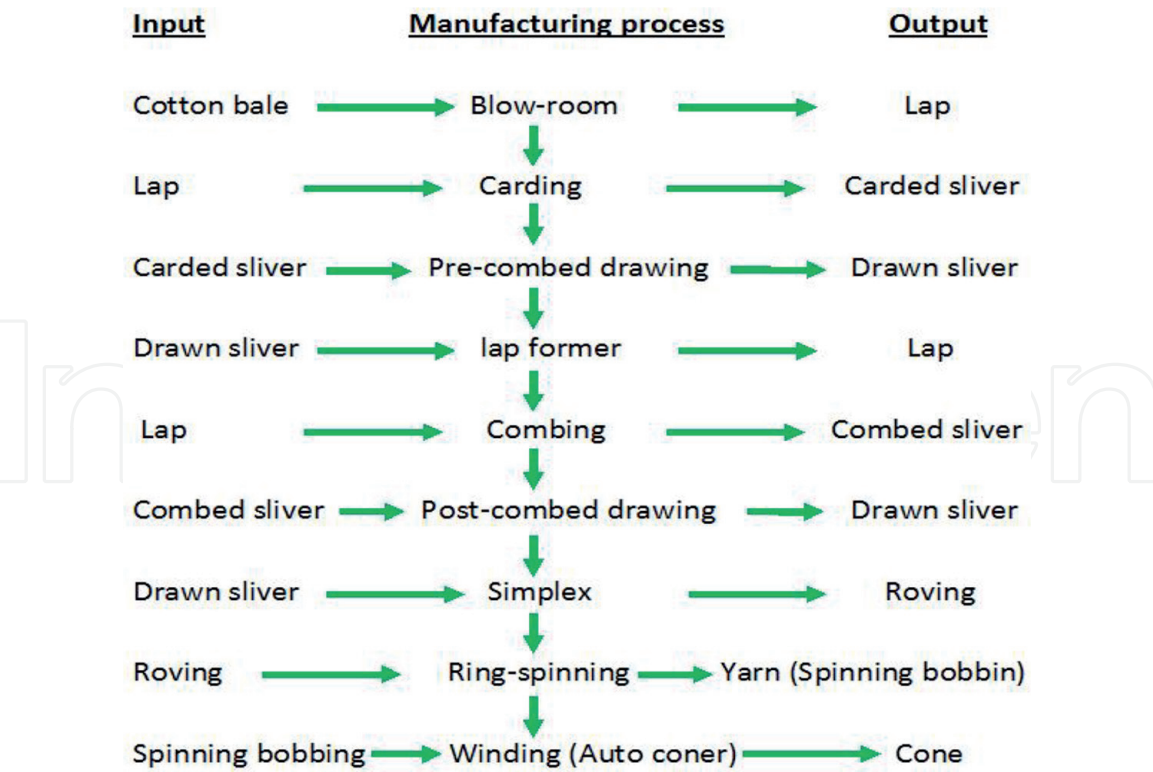


Figure 4.
Processing stages in cotton yarn manufacturing [8].

Several interesting works on the production of yarn are available that provide details of the material processing and technological control. Introductory spinning technology is described by Lawrence [10]. It covers the rudiments of staple-yarn technology, the manufacturing process, the raw materials, and the production processes for short-staple, worsted, semi-worsted, woolen spinning, doubling, and specialty yarn. Some of the useful advanced topics discussed are staple-yarn technology, including new development in fiber preparation technology, carding technology, roller drafting, ring spinning, open-end rotor spinning, and air-jet spinning.

Peter described the yarn production technology in combination with the economics [11]. The study is useful for yarn manufacturing and its development in the textile industry. Important topics covered include review of yarn production, filament yarn production, carding and prior processes for short-staple fibers, sliver preparation, short-staple spinning, long-staple spinning, post-spinning processes, quality control, and economics of staple-yarn production.

3.2 Fabric manufacturing

Textile fabric is at least a two-dimensional structure produced by fiber/yarn interlacing. The interlaced fibrous structure mainly used is woven, nonwoven, and knitted. Traditionally, the weaving technology was the principal source for fabric production.

The important types of woven fabric produced are the basic weaves, such as plain or tabby, twill, and satin, and the fancy weaves, including pile, jacquard, dobby, and gauze.

Knitted fabric is the second major type of fabric used following the woven. It has a characteristic of accommodating the body contour and provided the ease of movement. It is particularly a comfortable form of fabric structure for sports,

casual wear, and undergarment. Knitted fabrics include weft types and the warp types, raschel, and tricot.

Net, lace, and braid are other useful interlaced fabric structures. Nonwoven fabrics are rapidly increasing in market consumption. These fabrics are finding interesting uses in industrial and home applications. Nonwoven fabrics include materials produced by felting and bonding.

Laminating processes are also increasing in importance, and fairly recent developments include needle weaving and the sewing-knitting process.

3.3 Garment manufacturing

Garment is known as a piece of clothing. Garment design and manufacturing is the combination of art and technology.

Garment manufacturing has seen several advancements in design development, computer-aided manufacturing (CAD), and automation. However, the older version of garment manufacturing process is still the main theme today—that is, the cutting and joining of at least two pieces of fabric. The sewing machine has the function of joining woven or cut-knitted fabrics. Garments are mostly produced by sewing the pieces of fabric using a sewing machine. These machines are still based on the primary format used.

Today the important topics in the current garment manufacturing industry range over product development, production planning, and material selection. The selection of garment design, including computer-aided design, spreading, cutting, and sewing; joining techniques; and seamless garment construction are beneficial in meeting the consumer needs. The development in finishing, quality control, and care-labeling of garment are meeting the point-of-sale requirements.

3.4 Technical textile

Technical textile is an established domain of interdisciplinary application of textile products. Most of the major industrial sectors are benefiting the function of fiber material.

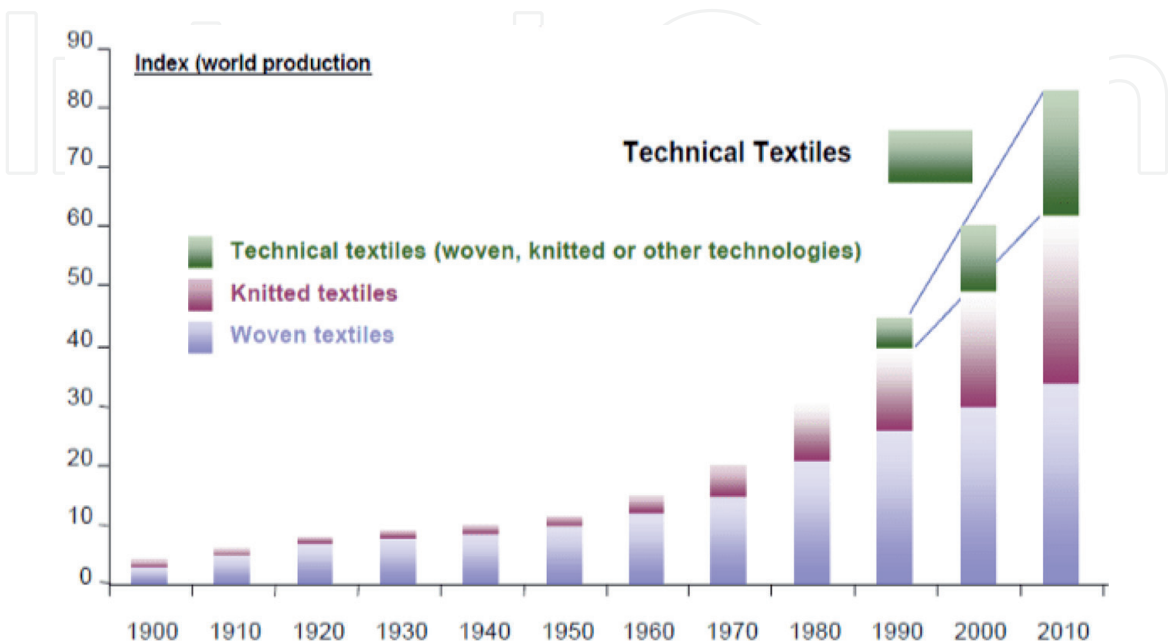


Figure 5. Emergence of technical textile products from 1990 and its growth with knitted and woven textiles [12].

Any technical textile is a fibrous structure or a textile product that is produced for technical performance rather than fashion or aesthetic requirements.

Currently, technical textiles occupy strong market consumption. It is significantly an important sector for industrial development in industrialized and developing countries.

There are 12 types of technical textile with example product application which may be outlined as under:

- Meditech—sanitary diapers, bandages, sutures, mosquito nets, heart valves, ligaments, etc.
- AgroTech—crop protection net, bird protection, water tank, etc.
- BuildTech—ropes, tarpaulin, concrete reinforcement, window blind, wall covering, etc.
- MobileTech—car airbags, aircraft seats, boat, seat belt, etc.
- ProTech—protective gloves, knife and bulletproof vest, flame-retardant and chemical-resistant clothing, etc.
- InduTech—conveyor belts, cordage, filtration media, etc.
- HomeTech—sofa and furniture fabric, floor covering, mattresses, pillow, etc.
- ClothTech—sun shade, parachute fabric, sewing threads, interlinings, etc.
- SportTech—sports shoe, swimsuit, sports nets, sleeping bags, sail cloths, etc.
- PackTech—tea bags, wrapping fabrics, jute sacks, etc.
- OekoTech or EcoTech (textiles in environment protection)—erosion protection, air cleaning, prevention of water pollution, waste treatment/recycling, etc.
- Geotech—nets for seashore and geo structures, mats, grids, composites, etc.

The emergence of technical textile products was realized in the 1990s, in addition to the conventional woven and knitted textile articles. However, since then technical textiles showed phenomenal growth (**Figure 5**) [12].

More recently, the global technical textile market has shown significant growth in consumption, and it is estimated to continue in the future. Technical textile market was estimated at USD 165.51 billion in 2017 and is projected to reach USD 203.7 billion by 2022. The CAGR of from 2017 to 2022 is indicated 5.89%.

4. Value addition in textile manufacturing

4.1 Pretreatment process

Any of fiber substrate including fiber/yarn, fabric, garment, technical textile, etc. may require a series of chemical processing to reduce the undesired content from the fiber. The selection of any pretreatment process, its composition, and methodology depends upon the end-use requirement of the textile product.

A pretreatment process is generally required to introduce two important value additions in textile substrate including:

- I. Removing the undesired content from the fiber mass including dust, coloring matters, undesired oils, lint, trash, etc.
- II. Imparting the required level of fiber property for subsequent processing of textile substrate. The required fiber property may include fabric whiteness, absorbency, softness, strength, weight, width, etc.

The pretreatment processes performed in conventional textile industry are sizing, desizing, scouring, bleaching, mercerization, washing, and heat setting. One or more of any of these processes are required for the textile substrate depending upon the end use of the textile.

Traditionally, the pretreatment process is performed on cotton, cellulose fibers, wool, and the blend of these fibers with synthetics and semisynthetics. Natural fibers including cotton and wool have natural impurities, and the purpose of pretreatment is primarily to remove undesired natural fiber content.

4.2 Coloration process

Dyeing, printing, and coating are the coloration processes to produce beautiful motif and color effect on textile. Printing and coating are limited to surface coloration and may be applied to most of the fiber types, natural fabrics, and synthetics. Approximately 10,000 different dyes and pigments are used industrially around the world [13].

Dyeing is the coloring effect throughout the cross section of fiber, and this effect can be produced on any form of textile substrate including fiber/yarn, fabric, garment, and clothing articles. However, any dyestuff is suitable for a particular type of fiber for dyeing.

Dyeing of textile substrate is performed using any of the dyestuff including reactive, direct, sulfur, vat, pigment, acid, and disperse, depending upon the dye-fiber system compatibility. The dyeing method used can be continuous, semicontinuous, and batching. Continuous dyeing technique is performed for large-scale production in the industry.

Fixation of dyestuff in fabric or garment should be significantly fast during the service life to provide resistance and durability against washing, heat, chemicals, soaping, rubbing, sunlight, etc.

Washing of the dyed fabric and the discharge of dye effluent may release 10–50% of dyestuff to the environment [13], and that is the environmental concern associated with the dyeing process. Globally, the inefficient dyeing and finishing process may result in the release of 200,000 tons of used dyestuff to the environment.

4.3 Special finishing process

Special finishing effects are required in textile fibers. The functional attributes of textile fibers are limited. Textile products are required to exhibit a variety of performance effects for end use. Crease recovery, flame retardant, water repellent, antibacteria, antistatic, moth proofing, softening, and hand-builder are the special finishing effects that can be produced in textile.

Conventionally, special finishing is performed following the coloration of textile; however, innovation has shown the possibility of performing special finishing

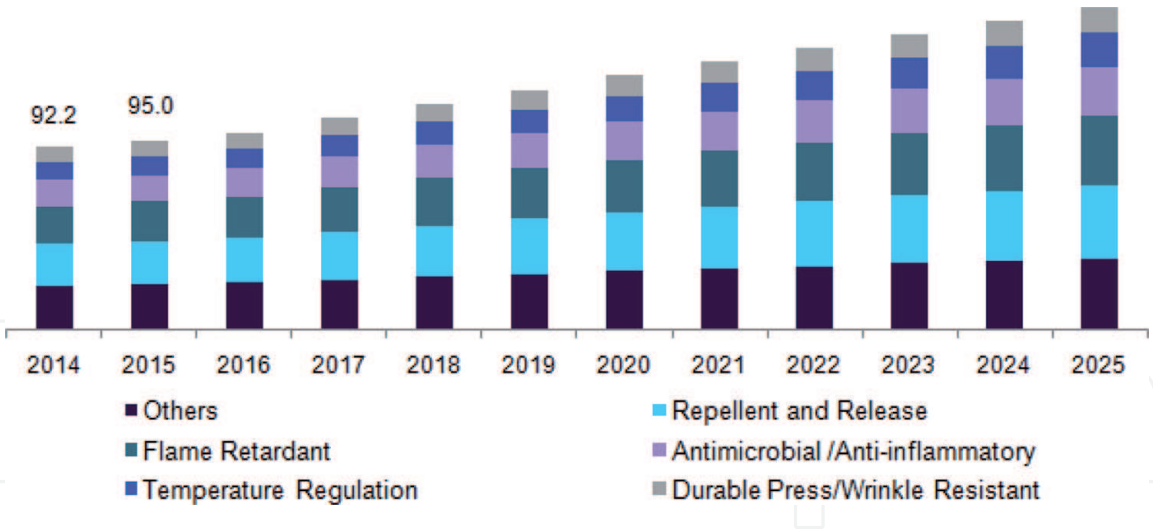


Figure 6.
Functional finish market growth (USD million) in the USA for 2014–2025 by product type (Grand View Research, USA [18]).

prior the coloration and special finishing in combination with the coloration process. The subject of investigating the alternating finishing and coloration processing sequences may offer the enhanced finish effects or coloration effects [14–17].

The global textile functional finishing is experiencing continuous growth, and the trend is forecasted to survive in the future. The market size was estimated at 114.2 million tons in 2015, and in terms of monetary value, it is expected to grow at a CAGR of 6.1% from 2016 to 2025 [18].

The USA is the major textile market for the consumption of special finishes. Grand View Research, USA, published future growth figures for special finishes that indicated almost all the important types of special finishes to rise in consumption till 2025 (**Figure 6**).

Over 50% supply of the special finishing agents is indicated to be through five major chemical companies including Dow Chemical Company; Bayer AG; BASF SE; Sumitomo Chemicals Co., Ltd.; and Huntsman International LLC. Asian countries including India, China, Bangladesh, and Vietnam are expected to see a flourishing market with the support of public policies.

Stronger environmental regulations, emission, and pollution control in the application, processing, and service life performance are the challenges in the use of special finishes [19].

5. Environment and textile manufacturing

All the environmental spheres, such as air, water and soil, are seriously affected by the textile manufacturing processes from fiber production to final fabric finishing. Consequently, a number of initiatives are introduced in textile industry by the public and private partnership to enhance the environment-friendly nature of textile processing.

Chemical used in fiber manufacturing and processing of textiles, effluent discharge from the textile dyeing, printing, and finishing, dust, short fibers, and lint released from the yarn manufacturing, volatiles and toxic gases released, etc., are the undesired effects to environment and human lives.

An estimation of the undesired effects to environment associated with the major processing units of textile industry can be presented based on the amount of consumption of chemicals, water and energy used. More the chemicals, water and

S. no	Process	Water (% consumption)	Energy (% consumption)	Chemicals (% consumption)
1	Yarn production	2	8	22
2	Fabric production	10	8	12
3	Wet processing (dyeing/ printing/finishing)	86	79	65
4	Garment production	2	5	1
5	Total	100	100	100

Table 1.
Water, energy and chemicals consumption in main processing sections of textile industry.

energy consumed in a textile process, higher is the possibility of undesired effects to our planet and living species breathing and breeding in the environment. **Table 1** shows an estimated percentage consumption of water, energy and chemicals in main textile processing sections.

Living species are directly or indirectly affected by the inhalation of toxic gases, consumption of contaminated water and food items, and the skin contact of toxic vapors and gases. The increasing realization of hazards associated with the textile manufacturing by the industrialized region in particular has resulted in the following important phenomena in textile sector:

1. conventional textile processing industries are clustered in developing countries;
2. technical textiles or textile processing with reduced environmental hazards grown in developed region; and
3. environmental standards, produced through the public and private participation, are increasing in practice in textile industries across the world to enhance the environment-friendly processes and products.

Water and chemicals are throughout the processing chain of textiles. Fiber manufacturing and processing, sizing, desizing, scouring, bleaching, mercerization, dyeing, printing, finishing etc., are known for water, chemical, and energy intensive nature. An increasing world population and the rising number of people to afford enhanced quantity of garments are elevating the production and processing of kilogram of fibers. Therefore, today, an individual is consuming more quantity of clothing, and there is an increasing population for higher consumption demand of clothing.

There may be than 1900 chemicals used in the production of clothing; where the European Union classified 165 the EU chemicals as hazardous to environment. An estimation made in 2015 for the assessment of environment hazard created by the global textile and clothing industry indicated the consumption of 79 billion of cubic meter of water. Large amount of this water is discharged into river and land without significant treatment in less developed countries. Toxic gaseous emission from textile processing is estimated to 1715 million tons of CO₂, and material waste is 92 million. If the processes continue in similar situation till 2030, the indicated water, gas and waste hazard will increase by at least 50% [20].

There are 107 eco-labels for textiles presently used [21]. In several developing countries, the textile processing industries are following the practice of ecolabels,

and the voluntarily eco-standards to demonstrate the environment- friendly process and product. An important example is Oeko-Tex Series of Standards that may be briefly described as follows [22]:

I. STANDARD 100 by OEKO-TEX: It may be described as an independent testing and certification system for raw, semi-finished, and finished textile products through all the processing stages. This standard is particularly useful for legal regulations, for example on banned azo colorants, and harmful chemicals.

OEKO-TEX 100 Standard helps the processor and producer of textile product to demonstrate the compliance for legal regulations including those limiting the banned azo colorants, formaldehyde, pentachlorophenol, cadmium, nickel, etc., and the voluntarily prevention of harmful chemicals that are not legally regulated.

II. SUSTAINABLE TEXTILE PRODUCTION (STeP) by OEKO-TEX® is a certification system for brands, retail companies and manufacturers in the textile chain to inform the public that they performed sustainable manufacturing processes. Therefore, STeP certification is applicable to all the sections of textile processing sector including fiber production, yarn manufacturing, fabric manufacturing, and garment production.

Any processing unit certified with STeP Standard means it follows the environment- friendly processes, ensure health and safety practices, and implement socially sound working environment for all the staff and place.

III. ECO PASSPORT by OEKO-TEX® is another standard. It provided the testing and certification system for chemicals, colorants and auxiliaries used in the processing of textile fiber. A three-stage verification is exercised on chemicals applied in textile processing to demonstrate compliance to safety, sustainability and statutory regulation.

IV. DETOX TO ZERO by OEKO-TEX® is the standard to evaluate the chemical management system in the textile chain coupled with the waste water and sludge quality disposed to environment by a textile unit. This standard requires the verification through an independent source.

Detox to Zero Status Report of a textile unit for chemical management and waste water and sludge control is based on providing the parameters including management system and organization structure, compliance to the legal requirements for storage and handling of chemicals, environmental protection, health and safety of employees, and production process.

6. Conclusion

Textile fibers provided an integral component in modern society and physical structure known for human comfort and sustainability. Man is an ancient friend of fashion. The quest for better garment and apparel led to the development of textile fiber production and textile manufacturing process.

A textile manufacturing process involves the production or conversion of textile fiber through a defined process in a product. The resultant textile product can be a finished product ready for consumer market, or it may be an intermediate product to be used as an input (raw material) substance to produce another textile product.

In general the conventional post-fiber formation processes may mainly be classified as physical and chemical textile manufacturing processes. A physical textile manufacturing process is required to convert the textile fiber into yarn; nonwoven, woven, knitted, technical textile; special finishing effects; etc. The chemical textile manufacturing processes include sizing, desizing, scouring, bleaching, mercerization, dyeing, printing, special chemical finishing, etc.

The chapters in this book are to share the development work in yarn manufacturing, fabric manufacturing, garment, and technical textiles. It is a collection of research and academic works in areas of textile manufacturing by the authors with expert background in the topic. The content may serve as a useful learning through the research work and the literature review as the subject tutorial.

Conflict of interest

The author declares no conflict of interest in writing this chapter.

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