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On the Basis of Fibers and Textiles

Fibers are substances composed of continuous or discontinuous filaments. They are mainly used in making textiles for human wear, thus called textile fibers. Traditionally, textile fibers can be classified as nature fibers, chemical fibers, and functional fibers.

Nature fibers are textile fibers directly obtained from plants or animals that are originally natural or artificially cultivated. Their advantages are that they can be directly obtained from nature and have good moisture absorption, air permeability, and extensibility. Nevertheless, the wide application of nature fibers is restricted by its limited source, low yield, poor chemical stability, and low abrasion resistance, thus their inability to supply the fast-growing needs of human beings.

Chemical fibers refer to the fibrous object manufactured by artificial processing, which can be divided into synthetic fiber and regenerated fiber. Compared with nature fibers, chemical fibers exhibit superior light resistance, abrasion resistance, mildew resistance, and mothproof ability. Besides, their length, thickness, whiteness, and luster can be conveniently adjusted during the production process. Therefore, they can be an important complementary for nature fibers.

Furthermore, functional fibers refer to new types of fibers that have some special functions such as flame retardant, antistatic, anti-ultraviolet, etc., in addition to common physical and mechanical properties of ordinary fibers. Nowadays, functional fibers have been developed in order to endow chemical fibers with special functions such as antiflaming, hydrophile, and antistatic.

Textiles are products made by processing and interweaving textile fibers. These can be made into clothes, which can be utilized for covering the ugliness, adorning the beauty, keeping out cold wind, and protecting the body from insects. In addition to these basic functionalities of traditional textiles, people have been exploring functional textiles by weaving with functional fibers to endow clothes with more functions, like better skin protection, body temperature maintenance, decoration and aestheticism, etc.

Textile-Based Energy Harvesting and Storage Devices for Wearable Electronics, First Edition.
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This chapter mainly discusses the basis (such as definition, classification, and application) of fibers and textiles and the evolution process from classical functional fibers to intelligent fibers and textiles.

1.1 On the Basis of Fibers

Fibers usually refer to a soft slender body with a length-to-width ratio above 10^3 and thickness of several microns to hundreds of microns. Since fibers are mostly used to make textiles, they are also called textile fibers [1]. Traditionally, textile fibers are divided into nature fibers and chemical fibers, according to their sources of raw materials. In recent years, textile fibers with some special functions (such as flame retardant, hydrophilic, antistatic, anti-ultraviolet, etc.) have emerged, which are called functional fibers. The following section will mainly introduce the definitions, classifications, characteristics, and applications of nature fibers, chemical fibers, and functional fibers.

1.1.1 Nature Fibers

Nature fibers can be directly obtained from planted plants or animal hair and secretions. They are important material sources for the textile industry, of which the history can be dated back to the prehistoric times. Humans have begun to use nature fibers even since the Neolithic. They have been used in making clothings and life production equipment (such as ropes, nets, bags, etc.). According to the source of raw materials, nature fibers can be divided into cotton fiber, hemp fiber, wool fiber, and silk fiber [1].

The first type of nature fiber is cotton fibers. They are single-cell material that grow on cotton seeds and lengthen first and then thicken deposits to mature (Figure 1.1a).[1] In addition, Figure 1.1b shows the scanning electron microscope (SEM) of cotton fibers.[2] The advantages of cotton fibers are that they have slender and soft texture and good moisture absorption, strong alkali resistance, organic solvent resistance, and heat resistance. Therefore, the applications of cotton fibers are suitable for making all kinds of clothes as shown in Figure 1.1c, furniture cloths and industrial cloths (https://site.douban.com/108216/widget/notes/181120/note/146893919).

The second type of nature fiber is hemp fibers. They refer to fibers that are obtained from a variety of hemp plants, including phloem fibers in the cortex of annual or perennial herbs, dicotyledonous plants, and leaf fibers in monocotyledonous plants (Figure 1.2a).[3] Also, Figure 1.2b shows the SEM of hemp fibers [2]. The advantages of hemp fibers are that they have good hygroscopicity, high strength, and low denaturation ability, as well as being very pleasantly cool. The applications of hemp fibers are that they can be used as textile materials to woven into various

1 http://www.xjxnw.com/c/2017-06-15/1215397.shtml
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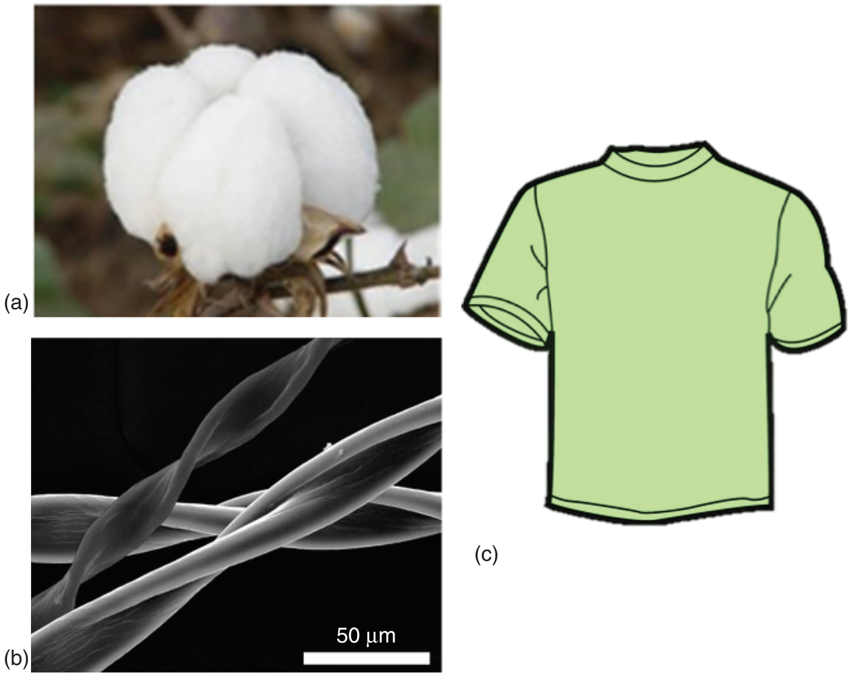

Figure 1.1 Cotton fibers. (a) Photographs of cotton fibers. (b) The SEM of cotton fibers. (c) Fashion clothing made of cotton fibers. Source: From Glenn Morrison et al. (2015), Figure 00 (p.149)/with permission of Elsevier. https://doi.org/10.1016/j.atmosenv.2015.05.051.

cool linen cloths, summer cloths, spinning ropes, and sacks for packaging as shown in Figure 1.2c.[4]

The third type of nature fiber is wool fibers that are developed from cells on sheep skin (Figure 1.3a).[5] Therefore, sheep wool is the most important textile wool fibers. Figure 1.3b shows the SEM of wool fibers [3]. The advantages of wool fibers are that they have soft and flexible texture and excellent warmth retention, so the applications of these are that they can be used in making woolen cloths, woolen yarns, blankets, felts, and other textiles. In addition, because wool fibers have the characteristics of good warmth retention and comfortable wearing, they are mostly used in autumn and winter clothings as shown in Figure 1.3c.

The fourth type of nature fiber is silk. It is a kind of continuous long fiber, which is solidified by silk liquid secreted by mature silkworm (Figure 1.4a).[6] In addition, Figure 1.4b shows the SEM of silk [4]. The advantages of silk are that it is light, fit, soft, smooth, and breathable and has gorgeous color, luster, elegance, and comfort. Additionally, silk is the mildest, softest, and thinnest nature fiber. The applications of silk are that it is used for silk weaving and then processed into a variety of silk

4 http://www.pibu.com/news/show-17833.html
5 http://www.czeps.cn/nongyechangshi/10387.html
6 https://baike.baidu.com/tashuo/browse/content?id=69510a16e826351b68c4ec14&fr=vipping

Figure 1.2 Hemp fibers. (a) Photographs of hemp fibers. (b) The SEM of hemp fibers. Source: Mwaikambo and Ansell [2]. (c) Photographs of spinning ropes and sacks for packaging.

textiles with different styles and finally made into silk products, clothing as shown in (Figure 1.4c), bedding, and other commodities (http://art.cfw.cn/news/153346-1.html).

1.1.2 Chemical Fibers

With the increase of human population and clothing requirements, limited natural resources are far from meeting with people's needs. As complementary to nature fibers, people have begun to consider the use of chemical fiber to address the shortage issue of cotton, silk, and wool. As a matter of fact, the use of chemical fibers has been started from the end of the nineteenth century. In addition, the period from the end of the nineteenth century to the 1930s of the twentieth century was a fast developing stage for the innovation of chemical fibers.

Chemical fibers are fibers made from natural or synthetic polymer compounds through chemical processing. According to the different sources of raw materials and processing methods, they can be divided into synthetic fibers and regenerated fibers.

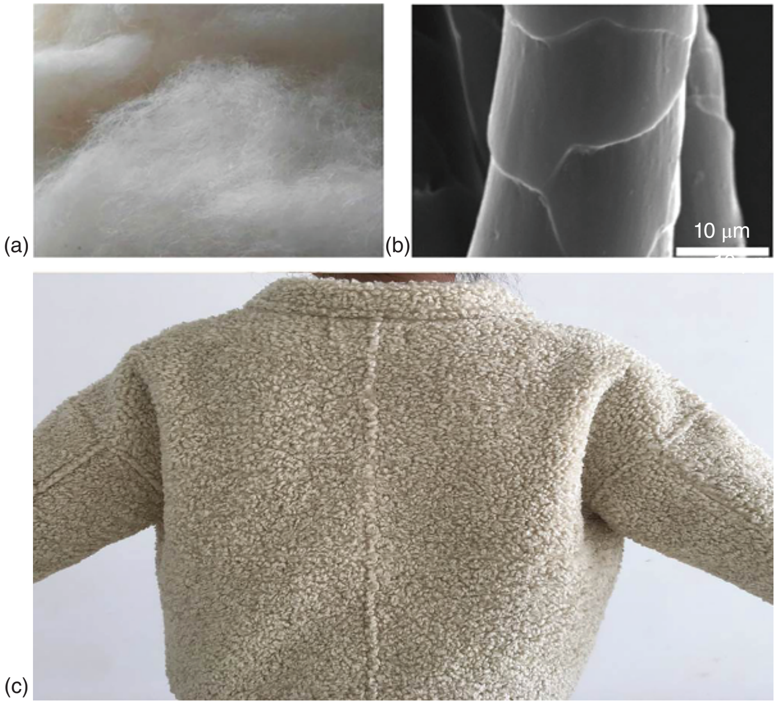

Figure 1.3 Wool fibers. (a) Photographs of wool fibers. (b) The SEM of wool fibers. Source: Long et al. [3]. (c) Photograph of wool fibers used in autumn and winter clothing.

Synthetic fibers are chemical fibers made from synthetic polymer compounds. Organic polymer compounds are synthesized by the addition polymerization reaction or condensation polymerization reaction with small molecular organic compounds as raw materials. People have developed various types of synthetic fibers for textile use, including polyester, nylon, acrylic, and vinylon.

Polyester is made from polyethylene terephthalate, which is produced by the condensation polymerization of terephthalic acid or dimethyl terephthalate and ethylene glycol (Figure 1.5a). The advantages of polyesters are that they have high strength, good elasticity, heat resistance, and density resistance. The applications of polyesters are that they are widely used in the manufacture of clothing and industrial products.

Nylon is linear structure polymer formed by amide bonds and several methylene groups (Figure 1.5b). The advantages of nylons are that they have strong abrasion resistance, ranking first among of all fibers. The applications of nylons are that they can be blended or purely spun into various medical and knitted products.

Acrylic is synthetic fiber made by copolymerization of acrylonitrile with other monomers, of which the acrylonitrile content is usually more than 85% (Figure 1.5c). The advantages of acrylics are that they have good elasticity and excellent lightfastness. Besides, their strengths will decrease by <20% in the

Figure 1.4 Silk. (a) Photographs of silk fibers. (b) The SEM of silk fibers. Source: Fink and Zha [4]. (c) Photographs of silk clothing. Source: From Andrea et al. (2016), Figure 01 (p.186)/with permission of Elsevier. https://doi.org/10.1016/j.saa.2015.10.024.

summer. Therefore, the applications of acrylics are that they can be used for curtains, tarpaulins, clothing, etc.

Vinylon is made by polymerization of vinyl alcohol acetate, which was usually alcoholyzed to obtain polyvinyl alcohol. After spinning, it can be treated with formaldehyde to obtain heat-resistant water-resistant vinylon (Figure 1.5d).[7] The advantages of vinylons are that they have good moisture absorption and air permeability, and its moisture absorption rate is the strongest among synthetic fibers, ranging from 4.5% to 5%. The applications of vinylon are that they are used to make knitted fabrics such as muslin, poplin, corduroy, work clothes, underwear, cotton sweaters, sweatshirts, etc. They can also be used for packaging materials, tarpaulins, canvas, fishing nets, surgical sutures, filter material, etc.

The second chemical fibers are regenerated fibers. They refer to the textile fibers obtained by using natural polymer compounds such as cellulose and protein as raw materials. After chemically processed into a concentrated polymer solution, they are

7 http://www.texindex.com.cn/buy/484056.html

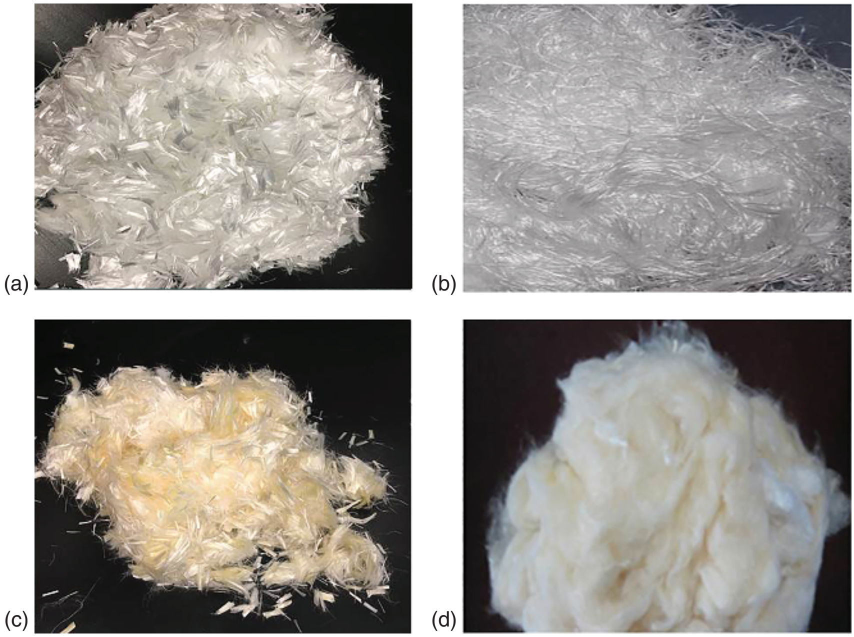

Figure 1.5 Four kinds of synthetic fibers. Photographs of (a) polyester, (b) nylon, (c) acrylic, and (d) vinylon.

spined into fibers. There are many types of regenerated fibers, such as viscose fiber, bamboo fiber, and cuprammonium fiber.

Taking viscose fibers as an example, they are made of natural cotton linters and wood as raw materials, which are regenerated by separating natural cellulose through chemical reactions (Figure 1.6a).[8] The transverse morphological characteristics of viscose fibers are shown in Figure 1.6b [5]. Viscose fibers exhibit good moisture absorptions and spinnability, better dyeability, and antistatic resistance. The preparation process of viscose fiber can be divided to three steps. First, plant cellulose was alkalized into alkali cellulose; second, alkali cellulose was reacted with carbon disulfide to generate cellulose xanthate; and third, cellulose xanthate was dissolved in dilute alkali solution and wet-spined to obtain fibers. Viscose fibers are often blended or interwoven with cotton, wool, or various synthetic fibers and used in various clothing and decorative textiles as shown in Figure 1.6c[9] because of their good moisture absorption, comfortable wearing, and excellent spinnability.

1.1.3 Classical Functional Fibers

Functional fibers refer to a new type of fibers that they are given special functions to the fibers through special surface processing technology or adding a certain

8 https://www.sohu.com/a/395160376_527026
9 http://www.yzzao.com/news/show.php?itemid=439

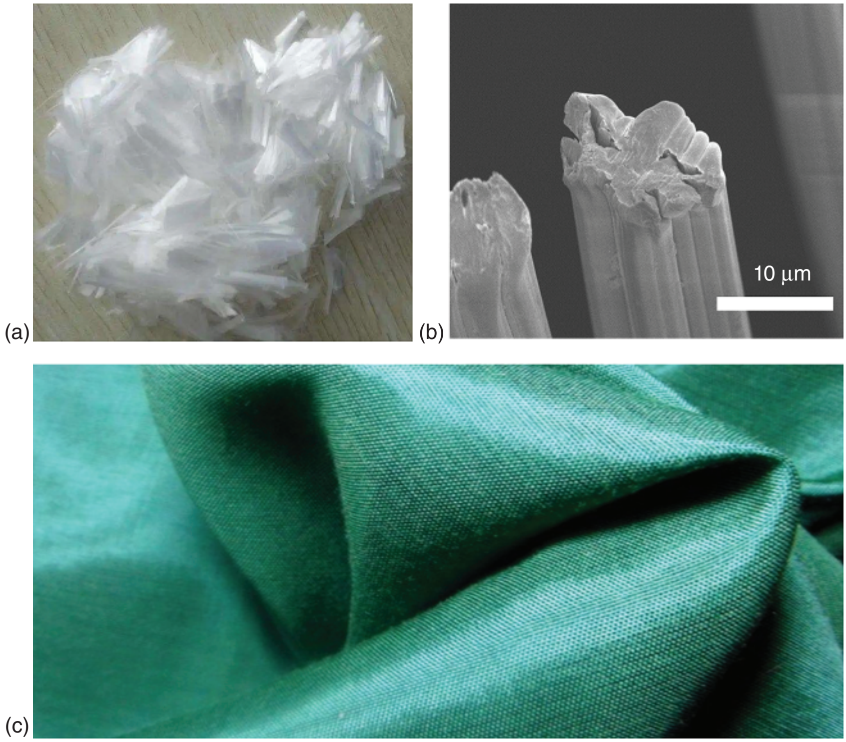

Figure 1.6 The regenerated fibers. (a) Photographs of viscose fibers. (b) The transverse morphological characteristics of viscose fibers. Source: Chi and Chen [5]. (c) Photographs of decorative textiles.

functional additive. They have been developed in order to endow chemical fibers with special functions such as antiflaming, hydrophile, and antistatic. There are many types of functional fibers such as flame-retardant fibers, the hydrophilic fibers, and the antistatic fibers.

Firstly, flame-retardant fibers refer to fibers that they can reduce the flammability of fiber materials in the flame and slow down the spread of the flame, so that they can extinguish themselves quickly after leaving the flame and no longer smolder. The flame-retardant mechanism is aiming to prevent the thermal decomposition of fiber and inhibit the generation of combustible gas. Therefore, it will block the thermal feedback loop or the air supply, which would then eliminate or reduce the three key elements of combustion (combustible substances, temperature, oxygen) and finally achieve the purpose of flame retardancy. The advantages of flame-retardant fibers are that they have good flame-retardant properties. Furthermore, the applications of flame-retardant fibers are mainly used for high-temperature work clothes, space suits, national defense clothing, and fireproof clothing for firefighters.

The preparation of flame-retardant fibers includes two methods: adding thermal-stable function group and compositing with flame-retardant materials [6]. On the one hand, adding thermal-stable function group can be achieved by adding aromatic rings or aromatic heterocycles to the macromolecular chain, which would increase the rigidity of the molecular chain and the density and cohesion of the macromolecular chain. This method has four goals, including increasing the thermal cracking temperature, inhibiting the generation of combustible gas, increasing the degree of carbonization, and making the fiber difficult to burn. On the other hand, compositing is to add flame retardant to spinning melt or slurry and then spin to make flame-retardant fibers. For example, Jung et al. [7] reported on a fiber modification methods to use keratinous fibers as the host material for creating an effective flame retardant as shown in Figure 1.7a. A simple solution-based treatment to implant amine phosphate and phosphoric acid in the fiber through sequential monomer infiltration is found to be significantly effective for applying flame retardancy and reducing the flammability of polymeric materials. As shown in Figure 1.7b, after the flame-retardant fiber modification, polypropylene (PP) shows significantly improved flame retardancy to achieve V-0 grade and >70% reduced peak heat release rate in vertical burning and cone-calorimeter tests, respectively.

Secondly, hydrophilic fibers are highly hygroscopic fibers. Hydrophilicity refers to the ability of fibers to absorb water and transport water to neighboring fibers. The mechanism of hydrophilic fibers is that there are a certain number of strong polar groups (such as —OH, —NH, C=O, etc.) on the macromolecular chain, which can form hydrogen bonds with water molecules. The edges of the amorphous region and the crystalline region are relatively large, the molecular structure is relatively loose, and water molecules easily penetrate into the tiny gaps on the fiber surface. The advantages of hydrophilic fibers are that the textiles made of hydrophilic fibers can emit water vapor discharged from the human body in time, so that the user feels comfortable, without the bad feeling of stuffiness and airtightness. The applications of hydrophilic fibers are that they are suitable for making underwear fabrics and summer cool fabrics and are also often used to blend with hydrophobic synthetic fibers to improve the consumption of synthetic fibers.

The preparation of hydrophilic fibers includes two methods: chemical methods and physical methods. On the one hand, chemical methods include copolymerization with hydrophilic monomers, graft modification of hydrophilic monomers, and hydrophilic treatment of fiber surface. On the other hand, physical methods include endowing the fibers with a porous structure, roughening the surface, and introducing heteromorphosis fibers. For example, Song et al. [8] used one-step process that was developed to generate hydrophilic coating on polytetrafluoroethylene (PTFE) hollow fiber membranes based on co-deposition of polymerized dopamine (PDA) and poly(ethyleneimine) (PEI) from aqueous solutions as shown in Figure 1.8a. PDA and PEI were successfully deposited on PTFE membranes while the hydrophilicity and wettability of the modified membrane were greatly improved. The modified PTFE membranes showed high water permeate fluxes, good long-term stability, and durability in strong acidic aqueous solution. Figure 1.8b shows the photographs of the modified PTFE membranes with different reaction time.

Thirdly, antistatic fibers are fibers that improve the electrical conductivity of the fiber by improving the moisture absorption of the surface of the fiber. The antistatic mechanism of the antistatic fiber is to leak most of the static electricity generated by

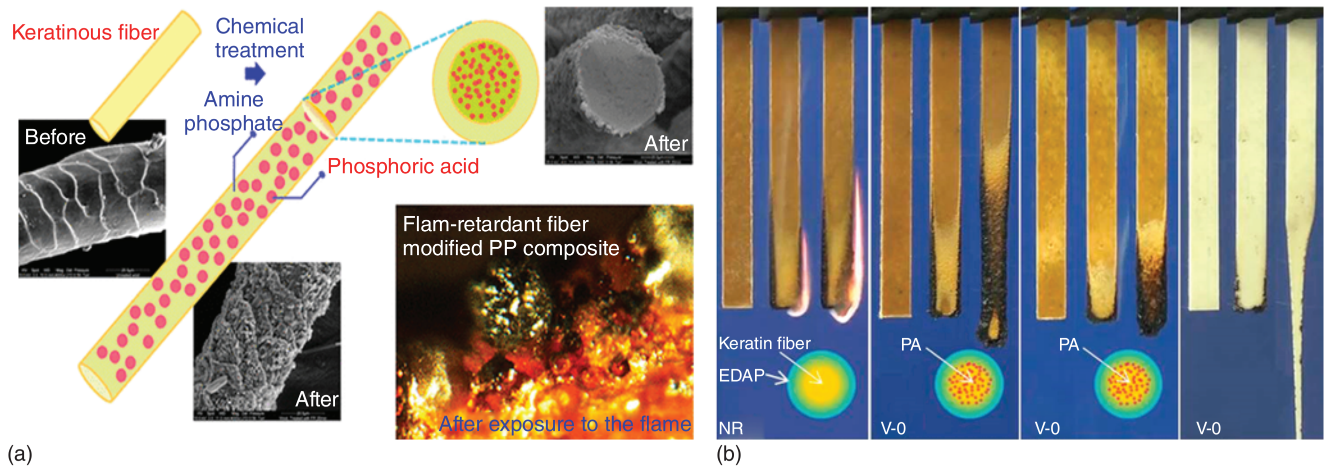

Figure 1.7 The flame retardant fibers. (a) Schematic diagram of fabrication of FR wool and SEM images of before and after wool surface treatment. (b) Captured images during the vertical burning test. Source: (a) Jung and Debes [7]. © 2018, American Chemical Society, (b) Jung and Debes [7].

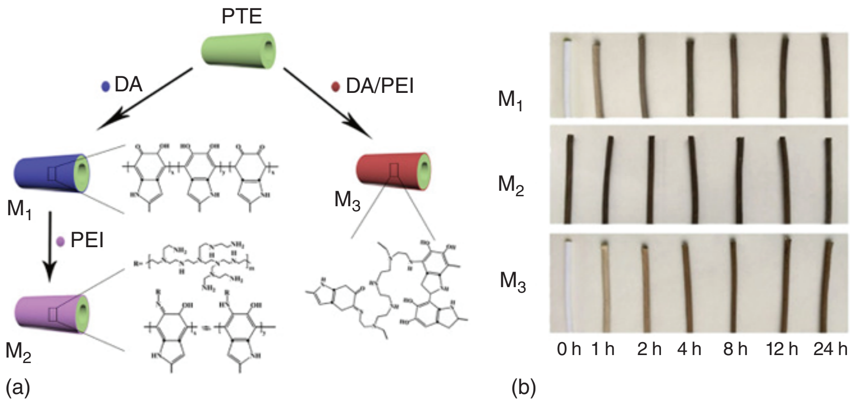

Figure 1.8 The hydrophilic fibers. (a) Schematic illustration for the modification of PTFE membranes. M_1, PTFE membranes coated by PDA; M_2, M_1 coated by PEI; and M_3, PTFE membranes co-deposited by DA/PEI. (b) Photographs of the modified PTFE membranes with different reaction time. Source: Song et al. [8]. © 2017, Elsevier.

moisture absorption, using the leakage effect. It needs to absorb moisture in the environment to increase the amount of static electricity leakage, so it is highly dependent on environmental humidity, and the general relative humidity is more than 40%. The advantages of antistatic fibers are that they are not easy to accumulate static charges, so they are often used in the processing all kinds of various clothing, carpets, mine conveyor belts, automotive interior decoration products, and special dust-free, sterile, and static-free work clothes.

The preparation of antistatic fibers includes four methods: (i) surface coating with antistatic agent, (ii) surface modifying with hydrophilic polymer finishing agent, (iii) co-spinning of ordinary polymer and antistatic polymer (such as polyethylene glycol, sodium alkyl sulfonate, etc.), and (iv) copolymering with antistatic monomer. For example, Gu et al. [9] synthesized PP/glass fiber (GF) composites showing excellent antistatic performance, which were prepared by a simple melt process blending PP with GF and a small amount of organic salts (OSs) as shown in Figure 1.9a. Also, Figure 1.9b shows schematic of the GF network and the surface absorption of OSs on the surface of GF. It was found that the GF and OSs exhibited significant synergistic effects on the antistatic performance and the mechanical properties of the composites. The GF network in the PP matrix provided perfect orbits for the movement of ions, inducing the excellent antistatic performance exhibited by the PP/GF composites at an OS loading of as low as 0.25 wt% when the GF formed a network in the PP matrix.

1.2 On the Basis of Textiles

Textiles are products made by processing and weaving textile fibers. Textiles can be divided into traditional textiles and functional textiles. Traditional textiles were basically utilized for covering the ugliness, adorning the beauty, keeping out cold

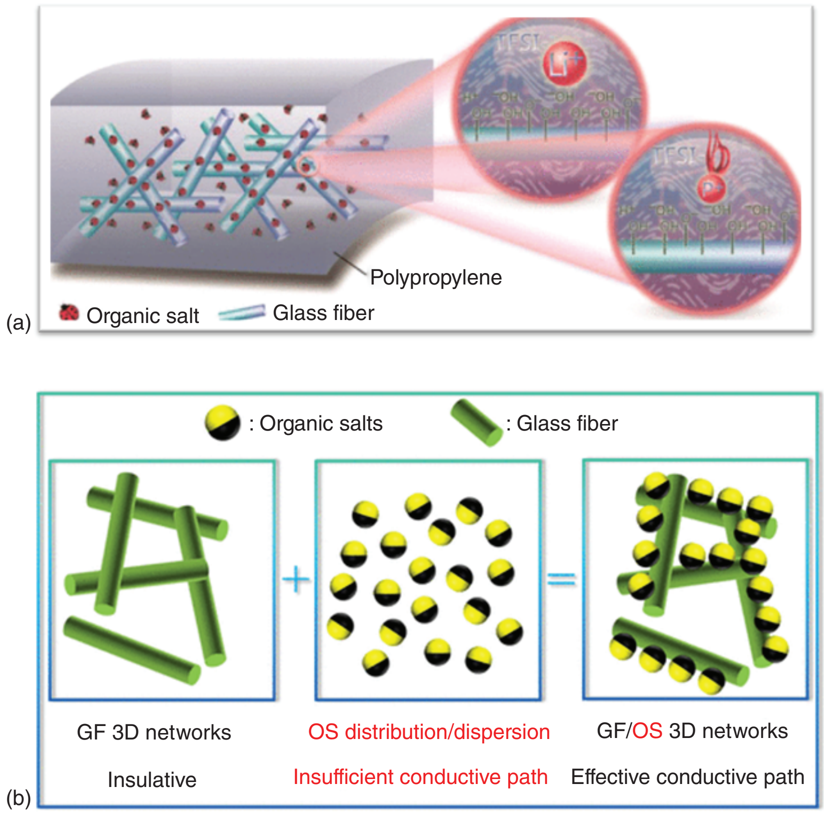

Figure 1.9 The antistatic fibers. (a) Polypropylene (PP)/glass fiber (GF) composites add a small amount of organic salts (OSs). (b) Schematic of the GF network and the surface absorption of OSs on the surface of GF. Source: Gu et al. [9]. © 2017, American Chemical Society.

wind, and protecting the body from insects. With the increase of human needs, traditional textiles could not meet with requirements of healthcare, protection, comfort, and medical and environmental protections. Therefore, various functional textiles (such as flame-retardant textiles, waterproof and moisture-permeable textiles, and antistatic textiles) begin to emerge and have become a trend in textile development.

This section will introduce the definition, classification, characteristics, and applications of both traditional textiles and functional textiles.

1.2.1 Traditional Textiles

Textiles can be seen everywhere in daily life, and their application fields include clothing textiles, household (decorative) textiles, and industrial textiles. Traditional textiles are objects that are formed by interspersing, interlacing, and entangling textile fibers and yarns in a weaving processing way. According to the production

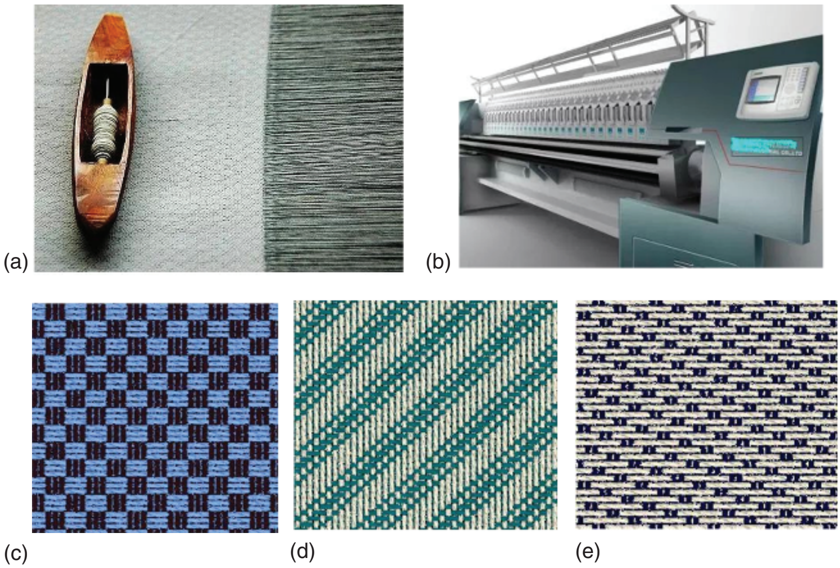

Figure 1.10 Description of woven fabric. Photographs of (a) woven fabric and (b) weaving machine of woven fabric. The organization structures of (c) plain weave, (d) twill weave and (e) satin weave.

methods, traditional textiles can be divided into woven fabrics, knitted fabrics, and nonwoven fabrics.

Firstly, woven fabrics (Figure 1.10a)[10] are made of two systems of vertical and horizontal yarns that are arranged vertically and interwoven according to certain rules on the loom (Figure 1.10b).[11] These fabrics exhibit stable structure, smooth cloth surface, and neat appearance. They have been used in all kinds of clothing, especially suitable for all kinds of outerwear and shirts. According to the organization structure, woven fabrics include plain weave, twill weave, and satin weave.

Plain weave is made up of warp and weft interlaced in a pattern of up and down (Figure 1.10c).[12] The characteristics of plain weave are that the numerator represents the warp yarn organization point and the denominator represents the weft yarn organization point. Warp and weft yarns are interwoven with other yarns, with more interweaving points and more yarn buckling points. Among them, the numerator represents the warp organization point, and the denominator represents the weft organization point. The advantages of plain weave are that the fabric is firm, wear-resistant, stiff, and flat and has good air permeability. The disadvantages of plain weave are that the elasticity is relatively small and the gloss is average. The applications of plain weave are mostly used for yarn-dyed and high-end embroidery fabrics.

10 https://ss2.baidu.com/6ON1bjeh1BF3odCf/it/u=1969820724,1531930458&fm=27&gp=0.jpg
11 https://ss0.baidu.com/6ON1bjeh1BF3odCf/it/u=2850963774,3906526589&fm=27&gp=0.jpg
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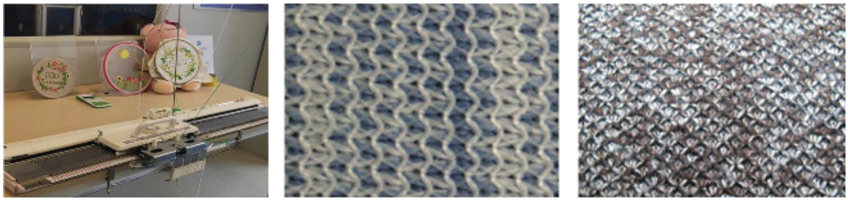

(a) (b) (c)

Figure 1.11 Description of knitted fabric. (a) Photograph of knitting machine, (b) warp knitted fabrics, and (c) weft knitted fabrics.

Twill weave is an organization in which weave points (or weft weave points) are continuous into diagonal lines (Figure 1.10d). The characteristics of twill weave are that the numerator represents the number of warp weave points on each yarn in the tissue cycle that has at least three warp and three weft threads and the denominator represents the number of weft weave points. These include gauze, twill, serge, etc. The advantage of twill weave is that there are obvious oblique lines, soft feel, strong three-dimensional sense, and good glossiness and elasticity. The disadvantages of these are poor wear resistance and fastness. The applications of twill weave are mostly used in printing, umbrella cover, sports shoes, and sportswear clips.

Satin weave consists of separate, discontinuous warp weave points (or weft weave points) that are regularly and evenly distributed in the tissue cycle (Figure 1.10e). The characteristics of satin weave are that the separate weave points on two adjacent warp yarns are far apart and independent and discontinuous and arranged in a certain order. The numerator represents the latitude and longitude of a complete organization, and the denominator represents the flying number that refers to the number of lines separated between two adjacent lines or two adjacent tissue points. These include horizontal tribute, straight tribute, soft satin, etc. The advantages of satin weave are that they have soft texture and smooth silk surface, good gloss, and most rich and luxurious. The disadvantage is that the floating length is longer and the fastness is the worst. The applications of satin weave are used for brocade, floral soft satin, handkerchiefs, etc.

Secondly, knitted fabrics are made of a group or groups of yarns connected to each other in circles according to certain rules on a knitting machine (Figure 1.11a). The advantages of knitted fabrics are that they have soft texture, good wrinkle resistance, and air permeability, as well as greater extensibility and elasticity. They are suitable for making underwear, tights, sportswear, etc. According to different knitting methods and fabric loop structures, knitted fabrics can be divided into warp knitted fabrics and weft knitted fabrics.

Warp knitted fabrics are fabrics formed by one or more groups of parallel yarns that are formed into loops along the warp direction of the fabric and are connected in series (Figure 1.11b).[13] This fabric passes through each yarn of a set of warp yarns to form only one or two stitches in one course and then forms stitches in the next course. The stitches formed by one yarn are arranged along the warp direction of the

13 http://info.texnet.com.cn/detail-760483.html

(a) (b)

Figure 1.12 Descriptions of nonwoven fabrics. (a) Photographs of nonwoven fabrics of different colors. (b) Photographs of weaving machine of nonwoven fabric.

knitted fabric. The advantages of warp knitted fabrics are that they have small extensibility, good elasticity, and low dispersibility. These are suitable for outer clothes, mosquito nets, fishing nets, flower headbands, towels, etc.

Weft knitted fabrics are fabrics in which one (or more) yarns are sequentially bent into loops along the weft direction of the knitted fabric, and the loops are sequentially wrapped (Figure 1.11c).[14] This is formed by feeding the raw material (yarn) into the knitting needles along the weft direction and then knitting them into loops in a certain order and forming them by stringing each other. The advantages of weft knitted fabrics are that they have greater horizontal extensibility, a certain degree of elasticity, and great dispersibility. At present, the applications of these are that they are used in underwear, pants, sweaters, etc.

Thirdly, nonwoven fabric refers to a product similar to cloth made by chemical (or hot melt) bonding with chemical fiber as the basic raw material, which is made without fiber weaving (Figure 1.12a).[15] These fabrics are formed by oriented or random arrangement of textile short fibers or filaments to form a web structure, which is then reinforced by mechanical and thermal bonding or chemical methods. Figure 1.12b shows the weaving machine of nonwoven fabrics.[16] These fabrics are moisture-proof, breathable, flexible, lightweight, noncombustible, easy to decompose, nontoxic, nonirritating, rich in color, low price, and recyclable. These are used for filling in clothes as linings and making disposable garments.

1.2.2 Classical Functional Textiles

People's pursuit of new textiles not only is satisfied with the basic functions of warmth and decoration but also has an increasing demand for healthy and environmentally friendly functional textiles. Therefore, functional textiles are constantly innovating in types.

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14 http://www.52bjw.cn/product-info/51429294.html
15 http://www.yzwufangbu.com
16 https://ss0.baidu.com/6ON1bjeh1BF3odCf/it/u=2995699824,2939041623&fm=15&gp=0.jpg

Functional textiles refer to textiles with special functions in addition to basic functions. In other words, these textiles not only have their own basic use values (such as comfortable wearing, conventional decoration, warmth, etc.) but also have some special functions of antibacterial, anti-mildew, antivirus, anti-mosquito, mothproof, flame retardant, and so on. According to different functional characteristics, classical functional textiles include flame-retardant textiles, waterproof and moisture-permeable textiles, and antistatic textiles.

Firstly, flame-retardant textiles are made of flame-retardant fibers or textiles that have undergone flame-retardant finishing, which have reduced flammability to varying degrees, and can significantly delay their burning rate during the combustion process, and can quickly self-extinguish after leaving the fire source. The advantages of flame-retardant textiles are that they are more washable and air permeable, as well as superior dyeing. Furthermore, the main characteristics of flame-retardant textiles are high limiting oxygen index. The applications of these textiles are that they can be used in making work clothes such as military protective combat uniforms, firefighting uniforms as shown in Figure 1.13a (https://www.51wendang.com/doc/d77bc160ad876beb14191011/2), steelmaking work clothes, welding work clothes, and medical protective clothing; curtains for public facilities, insulation cotton for exterior walls of buildings, and other flame-retardant products in industrial; and carpets, sofas, and curtains as shown in Figure 1.13b (http://www.hometex114.com/Leads/Detail_11_10604.html).

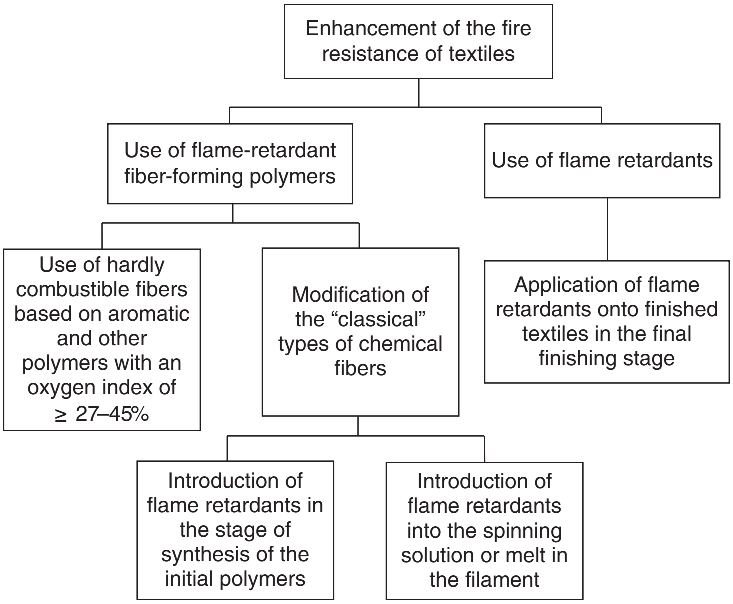
To prevent the burning process, it is sufficient to interfere with, or suppress, one or several of these subprocesses. This is the underlying principle of textile protection against fire via (i) application to the fabric of substances whose decomposition at the burning temperature releases noncombustible gases, (ii) formation on the fabric of a film isolating the oven fabric surface from atmospheric oxygen, (iii) chemical modification of the functional groups of the fiber, increasing the thermal stability of the macromolecular chains of the fiber, and (iv) use of combined methods of flame-retardant finishing of fabrics.

It is possible, in principle, to improve the fire resistance of textiles, i.e. to reduce their flammability or render them fire-resistant, via the creation of flame-retardant fiber-forming polymers or via the use of special agents, flame retardants, reducing the textile flammability (Scheme 1.1) [10].

It should be noted that fires today are much more dangerous than in the past, considering different burning temperatures and release of toxic substances. Therefore, the development of new low-toxic low-smoke substances and compositions reducing the flammability of polymeric materials will long remain an issue of much importance.

Secondly, waterproof and moisture-permeable textiles are the textile products that have integrated waterproof, moisture permeability, windproof, and warmth retention performance (Figure 1.14a) (https://www.sohu.com/a/229792964_297345). These textiles can not only meet with the wearing needs of people during activities in harsh environments such as severe cold, rain, snow, and windy weather, but also they are suitable for people's daily life requirements for raincoats. These can be

Figure 1.13 The applications of flame-retardant textiles. (a) Photograph of firefighting uniforms. Source: From Fent et al. (2014), Figure 01 (p.833)/CC BY/with permission of Oxford University Press. https://doi.org/10.1093/annhyg/meu036. (b) Photographs of curtains. Source: From Chunming Xu et al. (2011), Figure 01 (p.87)/with permission of John Wiley & Sons, Inc. https://doi.org/10.1002/fam.1089.



Scheme 1.1 Ways to reduce the flammability of textiles. Source: Vladimirtseva et al. [10]. © 2014, Spinger Nature.

(a) (b)

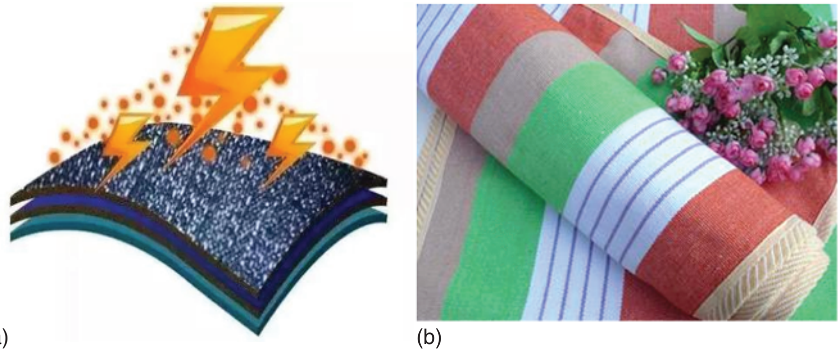
Figure 1.14 Waterproof and moisture-permeable textiles. (a) Photographs of waterproof and moisture-permeable textiles. Source: ag visuell/Adobe Stock. (b) Photographs of rainwear. Source: From Yating Wang et al. (2020), Figure 01 (p.03)/with permission of Elsevier. https://doi.org/10.1016/j.cej.2020.126222.

used to make sportswear, casual wear, rainwear as shown in Figure 1.14b,[17] sailing and water work clothes, firefighting clothing, etc.

The processing methods of waterproof and moisture-permeable textiles include the following three types:

(i) High-density fabric, which uses ultrafine cotton fiber or ultrafine synthetic fiber filament to be woven into a high-density fabric, so that the yarn gap of this fabric is small, preventing water droplets from passing.

17 https://guangdiu.com/detail.php?id=6379721



(a) (b)

Figure 1.15 Antistatic textiles. (a) Photographs of antistatic textiles. Source: https://www.sohu.com/a/229792964_297345. (b) Photographs of blankets.

(ii) Coated fabric, which throughs the use of dry or wet coating technology. Moreover, the pores on the surface of the fabric are closed or reduced to a certain extent by the coating agent, thereby obtaining water resistance.
(iii) Laminated fabric, which uses special adhesives and laminating process to laminate the microporous or hydrophilic film with waterproof and moisture-permeable function with ordinary fabrics to form a waterproof and moisture-permeable material.

Thirdly, antistatic textiles are textiles that are spun with conductive fibers or embedded in conductive filaments during weaving (Figure 1.15a) (https://www.sohu.com/a/229792964_297345). They can eliminate static electricity by themselves and can avoid electric shock and fire. These textiles can prevent the accumulation of static electricity on the surface of the textiles, and the static electricity on the surface of the human body made of antistatic textiles can be quickly released. They not only can solve the static electricity phenomenon in daily life but also can be used in work clothes or blankets (Figure 1.15b)[18] to play a role in special places to avoid safety accidents.

The preparation of antistatic textiles usually adopts the following three methods:

(i) Surface treatment method, which uses conductive metal salts or antistatic agents (such as quaternary ammonium salt, sodium alkyl sulfate, and polyol) and then through methods of spraying, dipping, and coating to carry out surface treatment (such as coating a conductive layer) of fibers and textiles.
(ii) Blending method, in which a small amount of conductive material (such as carbon black or metal oxide) or antistatic agent is added to the fiber and it is made by blending with the fiber stock solution.
(iii) Bulky chemical modification method, adding hydrophilic monomers (such as methyl acrylate) during the synthesis of fiber interpolymers and then synthesizing hydrophilic fibers through copolymerization to improve the moisture absorption of textiles and make them resistant to electrostatic performance.

18 http://379188.shop.cnlist.org/product/1509345.html

1.3 The Evolution from Classical Functional Fibers to Intelligent Fibers and Textiles

With the advancement of human civilization, people have been increasingly seeking for self-cognition, communication, and cooperation. On the one hand, human have tried to explore inward to get a better knowledge of ourselves such as memory, learning, and aging. On the other hand, we are falling into the incremental connection with others by relying on the portable electronics including smartphones and laptops. Those needs have accelerated the development of wearable electronic devices to deal with related information fast, accurately, directly, and conveniently. However, classical functional fibers cannot fulfill the new function requirements and failed to meet with the higher demands of human life, which then lead to the emerging of intelligent textiles.

Intelligent textiles can be defined as textiles device that are able to sense and respond to changes in their environment, rather than a type of fiber materials. Classical functional textiles can only play the role of protection, hygiene, and senses, but they cannot in terms of responding to their environment. Popular technologies for functionalizing textiles include vapor deposition, high energy beam processes, nanomaterial coatings, etc. Different from the classical functional textiles, intelligent textiles can sense and react to environmental conditions or stimuli according to thermal, mechanical, electrical, magnetic, or other bases [11]. Intelligent textiles can be prepared by dyeing and finishing of fabrics, weaving smart fibers into textiles, and integrating electronics into textiles. The development of intelligent fibers and intelligent textiles is an innovative combination of electronic devices and textiles, which provides a new idea for the human–machine interface in the future.

At present, many common intelligent textiles have been developed, which include shape memory textiles, intelligent temperature-regulating textiles, intelligent color-changing textiles, and electronic intelligent textiles, which will be introduced in details in the next section.

1.3.1 Shape Memory Fibers and Textiles

Shape memory fibers and textiles are a kind of special textiles with shape memory effect. The so-called shape memory effect means that the fiber or textile has a certain initial state under certain conditions, and when the external conditions change, the fiber or textile shape changes and fixes accordingly. When the external environment changes in a specific way, the fiber or textile can reversibly return to its initial state with its high ability to restore deformation. In addition, external conditions generally include thermal energy, light energy, electrical energy, external mechanical forces, and other physical factors and chemical factors such as pH, phase transition reactions, etc.

At present, most researches on shape memory materials are focused on shape memory polymers and shape memory alloys.

Firstly, shape memory polymer is a new type of functional polymer material, which includes polynorbornene, trans-polyisoprene, cross-linked polyethylene,

Figure 1.16 Photograph of shape memory fiber fashion designed by British designers. Source: From Dang et al. (2021), Figure 01 (p.03)/CC BY 3.0/with permission of IOP Publishing. https://doi.org/10.1088/1742-6596/1790/1/012084.

intercalated polyurethane, polyester, copolyimide, polyamide, etc. From the perspective of microphase structure, the shape memory polymer has a two-phase structure of "stationary phase" and "reversible phase." The "stationary phase" has the function of maintaining the shape of the solidified polymer. Supramolecular structure is manifested as the cross-linking, crystallization, glass state of macromolecules, or entanglement of polymer chains. The "reversible phase" is the variable part of the polymer. With the change of external conditions (mainly heat), the morphology changes, and the reversible phase undergoes crystal melting and formation or the reversible phase transition between glass and rubber. The advantages of shape memory polymer are that they are soft and easy to form and have better shape stability, a larger range of adjustable mechanical properties, etc.

The applications of shape memory materials in textiles are that these materials are made into filaments and then spun into yarns, and then shape memory yarn is woven into various shape memory polymer textiles. Shape memory polymer textiles are usually used in sportswear, mountaineering clothing, and tents. These kinds of clothing are easy to take care. After the clothing is wrinkled, it can be restored to the original flat state only by smoothing it by hand, and various styling treatments can be performed on the garments by manual grasping as shown in Figure 1.16 that is designed by British designers (https://ss2.baidu.com/6ON1bjeh1BF3odCf/it/u=2498880830,312056152&fm=27&gp=0.jpg).

Secondly, shape memory alloy is a special metal material, including nickel–titanium alloy, copper–zinc alloy, copper–tin alloy, nickel–titanium–copper alloy, and copper–zinc–aluminum alloy. This has the ability to deform and restore shape under certain heat treatment conditions. The basic principle of the alloy's shape memory effect is attributed to the thermal change of the metal crystal structure. Shape memory alloys have a certain transition temperature. Above the transition temperature, the metal crystal structure is stable; below the transition temperature,

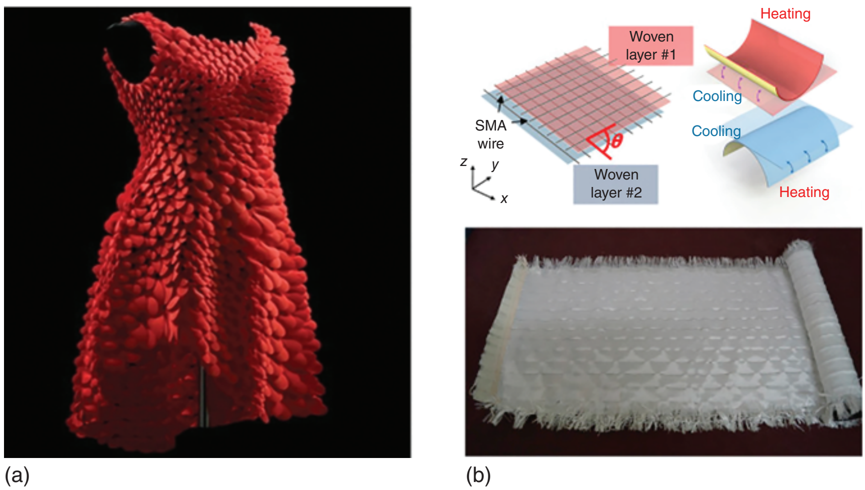


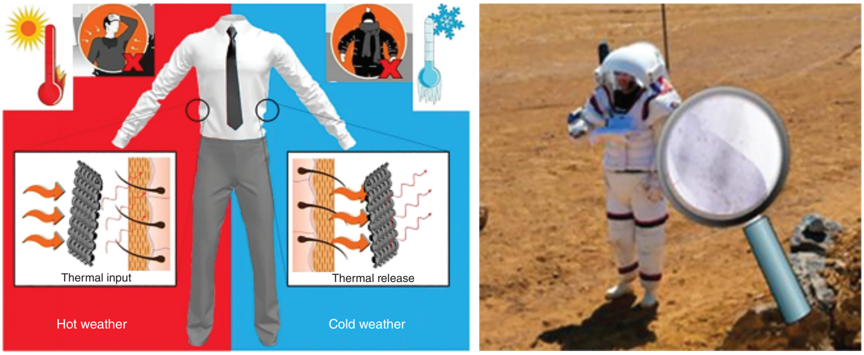
Figure 1.17 The applications of shape memory fibers and textiles. (a) Photograph of anti-wrinkle clothing. Source: Biswas et al. [12]. (b) Photograph of anti-scald clothing. Source: Han et al. [13].

the crystal is in an unstable structure state and deforms when subjected to external forces. When the heating temperature rises above the transformation temperature, the metal crystal will return to the shape of the stable structure state, which will cause the deformation and deformation recovery of the alloy fiber.

Shape memory alloy fiber or textile is made of shape memory alloy. At present, nickel–titanium alloys are the most used shape memory alloys in textiles because its fibers have a large deformation recovery rate, good stability, and good biocompatibility. For example, an Italian company recently launched a "smart shirt" that uses a fabric interwoven with nickel–titanium alloy wires and nylon and a woven fabric with five nylon wires and one nickel–titanium alloy wire. This shirt is used in the hot summer, the shape memory fiber is activated, and then the sleeves of the shirt will be automatically rolled up immediately. Furthermore, the sleeves can automatically recover when the temperature drops. In addition, this shirt is not afraid of wrinkling, even if it is crumpled into a wrinkled ball, the hot air blown by a hair dryer or the human body temperature will immediately restore it (Figure 1.17a) [12]. And the British textile agency processed and fixed nickel-titanium alloy fibers inside the garments when they developed anti-scald garments. Once they come into contact with high-temperature shape memory fibers, they will be excited to achieve the purpose of anti-scalding as shown in Figure 1.17b [13] (https://www.sohu.com/a/237181827_783093).

1.3.2 Intelligent Temperature-Regulating Fibers and Textiles

Intelligent temperature-regulating textiles are high-tech products developed by combining the phase change materials with the fiber and textile manufacturing technology. The advantages of intelligent temperature-regulating textiles are that



(a) (b)

Figure 1.18 The applications of intelligent temperature-regulating fibers and textiles. (a) Photograph of protective outerwear. Source: From Linghui Peng et al. (2019), Figure 01 (p.6416)/with permission of Springer Nature. https://doi.org/10.1007/s10570-019-02534-6. (b) Photograph of astronaut clothing. Source: From Malgorzata Holyńska et al. (2020), Figure 18 (p.24)/with permission of John Wiley and sons. https://doi.org/10.1002/admt.202000028.

they can adjust the micro-temperature between human body and external environment and improve the dress comfort of human body. The applications of intelligent temperature-regulating fibers are that they are used in textile industries such as protective outerwear shown in Figure 1.18a (https://www.sohu.com/a/203630756_368281) and astronaut clothing shown in Figure 1.18b (https://www.sohu.com/a/237181827_783093). These not only are a technological innovation in textile industry but also provide a guarantee for people working at extreme environmental temperatures.

The phase change material (such as simple salt, alkali metal and alloy, paraffin, fatty acid, and eutectic) is an important component of intelligent temperature-regulating textiles. Through specific technology, phase change materials are combined with textiles or fibers to realize the intelligent temperature regulation of textiles. When a substance undergoes a phase change, which is accompanied by heat absorption or heat release, the energy absorbed or released is called phase change heat. The mechanism of heat storage and temperature adjustment of phase change materials is that the solid–liquid reversible change occurs in the phase change material of the textiles according to the change of the ambient temperature of the outside. When the ambient temperature is increased, the stored heat is absorbed, and the phase change material is changed from the solid state to a liquid state. Also, when the temperature is reduced, the stored heat is discharged from a liquid state to a solid state. Therefore, the two-way temperature regulation of the textile is realized, and a comfortable temperature environment is created.

There are three commonly used manufacturing methods for intelligent temperature-regulating textiles:

(i) Hollow fiber filling method, which makes hollow fibers first and then immerse them in the phase change material solution to fill the hollow part of the fibers with the phase change material and finally close the ends of the fibers after drying. For example, the hollow fiber is immersed in polyethylene glycol solution to obtain a temperature-regulating fiber containing polyethylene glycol in the hollow part.

(ii) Spinning method, which adds phase change materials and additives to the spinning solution. For example, *n*-octadecane microcapsules are mixed with a polyacrylonitrile/vinylidene chloride copolymer solution, and the temperature-regulating fiber is prepared by a solution spinning process.

(iii) Fabric finishing method, which uses the padding method and coating method to finish the phase change material on the textile. Moreover, this method is simple and easy. For example, a blend of energy storage microcapsules and coating glue is coated on the surface of the fabric to make smart temperature-regulating textiles.

1.3.3 Intelligent Color-Changing Fibers and Textiles

Intelligent color-changing fibers and textiles refer to the fibers and textiles that can show different color with the change of external environment condition (such as light, temperature, electricity, etc.). The advantages of intelligent color-changing textiles are that they have good washing resistance and long-lasting color-changing effect. The applications of these are that they are used in textile, military, entertainment, anti-counterfeiting, and other fields because these are kinds of intelligent products with high added value and high efficiency. For example, they can be used in the production of fashion discoloration clothing and decorative fabrics and anti-counterfeiting field, which can be used as anti-counterfeiting materials and widely used in bills, documents, and trademarks and so on.

According to the external stimulus conditions, the color-changing textiles are mainly divided into photochromic textiles, thermochromic textiles, and electrochromic textiles.

Firstly, photochromic textiles refer to the textiles whose color change with the wavelength of light or the intensity of light. Photochromism is observed when there is a change in sunlight (UV radiation) exposure to a photochromic material. The chemical structure of a photochromic material is temporarily altered as a result of UV irradiation. This change in chemical structure leads to a shift in the absorption of electromagnetic waves to the visible part of the spectrum, upon which the color changes from colorless to colored. A reverse change in its chemical structure, and consequently in its electromagnetic wave absorption spectrum, can take place in the absence of UV rays. As a result, the material returns to its original colorless state.

The application of photochromic textiles adds new content to clothing fashion. More recently, British designer Amy Winters has created a sun-reactive dress by printing photochromic inks directly onto the fabric. The rainforest dress is white indoors but becomes purple when exposed to sunlight (Figure 1.19a) [14]. Photochromic textiles have also been used for military purposes to provide protection by camouflage and, by monitoring UV radiation, can be applied for solar protection.

Figure 1.19 The applications of photochromic textiles. (a) Amy Winter's photochromic "rainforest" dress expressing the effects without (left) and with (right) UV exposure. Source: Kelly and Cochrane [14]. (b) Photograph of photochromic textiles in fashion. Source: From Zidan Gong et al. (2019), Figure 02 (p.03)/CC BY/with permission of MDPI. https://doi.org/10.3390/ma12203311.

Figure 1.19b shows the photochromic textiles in fashion (https://m.sohu.com/a/374940893_559321).

Secondly, thermochromic textiles are made of a special thermal discoloration material. Thermochromism is observed when there is a change in heat exposure to a thermochromic material. Thermochromic materials change their molecular or supramolecular structure and absorption spectrum as a result of the variation in environmental temperature. The structural changes of thermochromic compounds may include rearrangement of molecules (e.g. cleavage of covalent bonds or changes in the spatial configuration of a molecule) and changes in crystalline structures.

The applications of thermochromic textiles have predominately been used for decorations and fashions. For example, a US kick-starter company by the name of

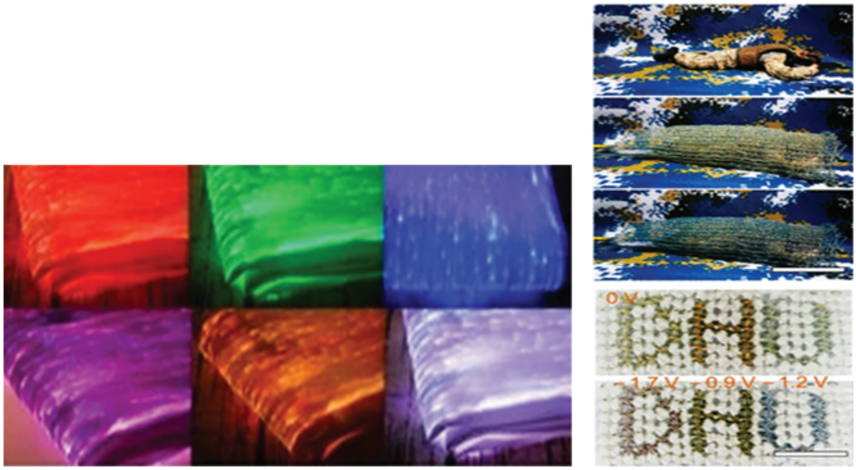
(a) (b)

Figure 1.20 The applications of thermochromic textiles. (a) Heat-sensitive color-changing textiles of Radiate Athletics' heat-sensitive sportswear and Shi Yuan's blossoming wallpaper. Source: Kelly and Cochrane [14]. (b) Photograph of Stone Island thermal response jacket. Source: From Zidan Gong et al. (2019), Figure 02 (p.03)/CC BY/with permission of MDPI. (https://doi.org/10.3390/ma12203311).

Radiate Athletics has applied thermochromic materials to sports clothes in order to monitor the body temperature of a person. When a person is working out, their body heats up, and consequently the fabric of the T-shirt, or other item of clothing, will change color (Figure 1.20a). Certain parts of the shirt will change color before others, therefore making it possible to determine which parts of your body are being exercised the most. As a result, the color-changing function of the sports clothing offers the ability to monitor and maximize your workout [14]. Figure 1.20b shows the Stone Island thermal response jacket (https://m.sohu.com/a/374940893_559321).

Thirdly, electrochromic textiles are kinds of textile materials whose color changes reversibly with the change of external electric field. Electrochromism is induced by a change in the electrical potential applied to an electrochromic material. Electrochromic materials experience a reversible change in color as a result of an electrochemical redox (i.e. oxidation and reduction) reaction. These require only a short electrical pulse in order to effect the color change. Due to the memory effect of electrochromic color changes, little or no input of power is required to retain the new color. Electrochromic displays are therefore far more economical in the consumption of power when compared with their light-emitting analogs. Additionally, there is no visual dependence on the viewing angle, and multiple colors, with high contrast, are available. The advantages of electrochromic textiles are that the light transmittance can be adjusted freely in a large range and have multi-color continuous change, storage memory functions, low driving color change voltage, simple power supply, power saving, less environmental impact, etc.

The applications of electrochromic textiles have great prospects in some special fields such as safety warnings, fashion clothing, decorations, and adaptive camouflage. For example, Thermochromic textiles are used for cloth of different colors



(a) (b)

Figure 1.21 The applications of thermochromic textiles: (a) Photograph of electrochromic cloth of different colors. Source: From Zidan Gong et al. (2019), Figure 02 (p.03)/CC BY/with permission of MDPI. https://doi.org/10.3390/ma12203311. (b) Digital photographs of electrochromic fibers or textiles in the colored/bleached states for proof-of-concept military camouflage. Source: (b) Fan et al. [15].

(Figure 1.21a) (https://doi.org/10.3390/ma12203311). Furthermore, in military stealth technology, human used electrochromic fibers and textiles to make the covering of color-changing dragon suit or gunsuit, achieving good results as shown in Figure 1.21b [15].

1.3.4 Wearable Electronic Intelligent Fibers and Textiles

Traditionally, the collection, analysis, storage, and transmission of signals are completed by an integrated electronic system based on printed circuit board (PCB), which has been implanted with rigid electronic components, such as sensors, didoes, transistor, switches, etc. However, integrated circuit (IC) boards, even though bendable or stretchable, still have body-adaptation problems for many people and were usually regarded as special medical measures, rather than the daily wearing habit, especially when people feel healthy.

Emerging wearable electronic intelligent textiles refer to highly intelligent textiles that can also function as the integrated electronic systems, information processing, computing, and other electronic functions. Until now, there are three technical solutions of integrating electronic components based on textiles: (i) embedding small electronic components or equipment on ordinary fabrics or fabric-type power sources, (ii) directly assembling flexible electronic devices based on fabric substrate, and (iii) weaving various fiber-shaped electronic devices into one textile.

In fact, the first two technical solutions are very similar to the PCB-based solution for conventional ICs.

For example, for the first technical solution, Fan and coworkers [16] wove fiber-shaped batteries with interwoven textile-type solar cell into one textile by

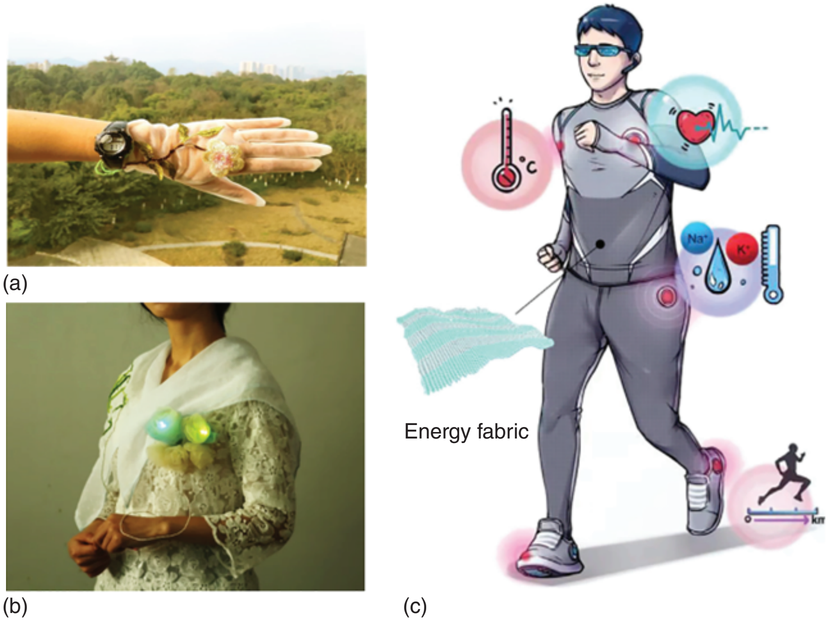


Figure 1.22 Integration of electronic devices into textiles. Demonstration of the energy fabric to serve as the power source for various portable electronics. (a) Electronic watch and (b) light-emitting diode (LED) lights. Source: Huang et al. [16]. (c) Illustration of an autonomous body area sensor network. Source: Zhang et al. [17]. © 2020, Elsevier.

couching embroidery or weaving. This energy textile can be reformed as a gauze glove, which can serve as both a fabric substrate and a portable power source for embedding with wearable electronics, such as sensors, LEDs, and electric watch (Figure 1.22a). With the appropriate appearance and pattern design, it can also be designed to a gauze kerchief, which can be worn around the body and power colorful light-emitting diode (LED) lights (Figure 1.22b) or decorations in stage performances. With a collection of compelling features, the wearable photo-rechargeable fabric paves a new way to sustainably power body area sensor networks for personalized healthcare [17]. As shown in Figure 1.22c, a body area sensor network is a collection of wearable/implantable biosensors that can be employed to continuously monitor human physiological signals for personalized healthcare. Given such features as lightweight, robustness, and cotton-like softness, the photo-rechargeable fabric integrated with sensor and communication components can act as autonomous textile sensor network for continuous human physiological, biomechanical, and ambient environmental monitoring, with the possibility of succeeding as a future medical application in the era of the Internet of Things.

For example, for the second technical solution, Peng and coworkers [18] integrated of the electronic components into textiles by a screen-printed process on the textile directly to form the patterned circuits (Figure 1.23a, b). Different electronic

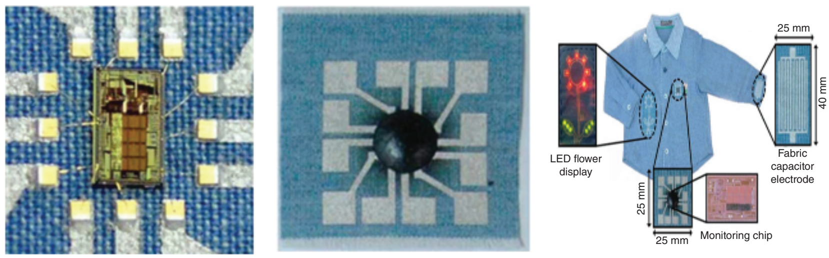


Figure 1.23 The screen-printed process. (a) Electronic component bonding on a P-FCB. (b) Electronic component packaging on a P-FCB. (c) System integration on P-FCB with capacitive sensor, chip, and LED display. Source: Adapted with permission from Wang et al. [18]. Copyright (2019) by WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim.

components, e.g. system-on-a-chip, chip capacitors, resistors, and LEDs, can be bonded directly on the textile lead frame (Figure 1.23c). Liquid molding epoxy was then coated on the chip after bonding process, which provided robust protection against stretching.

Compared with the first two technical solutions, intelligent textile woven from fiber-shaped electronic devices are soft and deformable, and the structure of textile can be designed into various patterns with high integration degrees. By integration of fiber-shaped electronic devices into textiles, it shows unique and attractive application prospects in the field of wearable/portable electronic products.

During the weaving process, there are two main assembling strategies for device units. The first strategy is to make complete fiber-shaped electronic devices, such as sensor, solar cells, lithium ion batteries, and light-emitting devices, and then integrate them into textiles through weaving or embroidery technologies. The second strategy is to weave fiber-shaped cathode and anode with an interlaced structure to directly construct textile-type electronic devices. Comparing with the first strategy, the second strategy has been verified by successfully fabricating solar cell textiles, in which the warp and weft yarns serve as the anode and modified cathode, respectively. As a matter of fact, Fan et al. have already presented a cloth-like 24/7 private AI nursing system based on fully interwoven IC fabric, for which both devices (Figure 1.24a) assembling and circuit wiring (Figure 1.24b) were completely accomplished along polymer wires or at their cross-nodes during weaving, rather than on a PCB. Figure 1.24c and 1.24d shows a designed interwoven IC textile and the practical interwoven IC textile, respectively. Such a body-fitted cloth has demonstrated its capabilities of uninterrupted physiological monitoring, signal amplifying, logic computing, and wireless communication, as an independent mobile electronic system for routine monitoring and emergency assistance.

Starting with the lightweight, low-cost polymer fibers and taking advantage of industrial weaving technology, flexible wearable electronic intelligent textiles are an increasingly expanding field that has raising value for both academicians and industry, in areas such as energy harvesting and storage, environment monitoring,

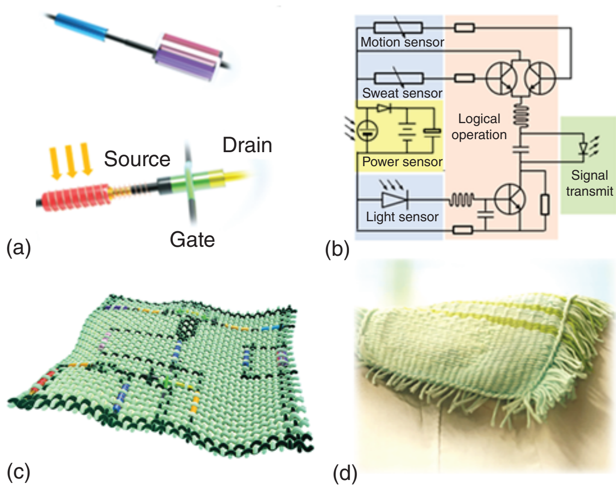


Figure 1.24 Integration of fiber-shaped electronic devices into textiles by interwoven IC. (a) Fiber-shaped field-effect transistor. (b) Design drawing of IC. (c) A designed interwoven IC textile. (d) The practical interwoven IC textile. Source: Based on Fan et al. [15].

healthcare systems, and entertainment products. Clothing is a feature of all human societies. Merging electronics and textiles is becoming increasingly important. Global industry giants have been exploring an efficient way of merging electronics with common cloth by pursuing an ultimate dream of "fabric computer" [19].

Although the integration of different functions of fibers has been widely demonstrated, the mismatch in material, structure, and fabrication requirement among the different kinds of devices still remains to be a critical barrier for practical applications. It is vital to develop efficient processing techniques to integrate different fiber electronic devices into textiles with a better and more comfortable human/textile interface design. Moreover, reliable connecting technique and IC are desired to achieve the higher integration of electronic textile. Apart from the problems mentioned above, safety issues are important for practical applications. Some fiber-shaped electronic devices such as batteries often require the use of flammable and toxic organic electrolytes, and they suffer from risks of fires and explosions induced by short circuit during deformation.

1.4 Conclusions

This chapter has discussed the definition, classification, characteristics, and applications of fibers, textiles, and intelligent textiles.

Fibers are closely related to every human life. Nature fibers such as silk and cotton were woven into textiles by human, which can keep human warm and comfortable. Because nature fibers are limited by natural conditions, they cannot meet with human needs, so people began to synthesize chemical fibers by processing methods, which appeared same as nature fibers but greatly enhanced human lives.

However, traditional textiles only have the basic functionalities, which can cover the ugliness and adorn the beauty, keep out the cold wind, and protect the body from insects. They cannot meet with human demands for healthcare, medicine, etc. Then, various functional fibers and textiles with special functions are constantly emerging, which are obtained through special processing of the original fibers or textiles.

Recently, textiles have faced a new challenge with the advancement of electronics and the Internet. Therefore, textiles are now expected to exhibit intelligent functionalities besides healthcare, protection, and medicine. Intelligent textiles are the product of the effective combination of high technology and traditional textile technology. They have broad market prospects and have great application potential in clothing, construction, military, etc., even though many new varieties are still under development.

In the near future, varieties of intelligent fibers and textiles will become more and more abundant, and the scope of application will become more and more extensive. The intelligent textiles can lead an important development direction and become a new economic growth point of the textile industry.

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