DOI 10.15302/J-SSCAE-2022.02.019

Industrial Textile Materials in China: Development Status, Demand and Countermeasure

Hou Xi [1], Li Shujia [2, 3], Ye He [1, 3], Yuan Ruwang [4] , Yang Jiancheng [4],Meng Zhuo [2, 3], Zhu Xianmin[1], Chen Ge [2, 3]

1. China Textile Machinery Association, Beijing 100028, China
2. Engineering Research Center of Advanced Textile Machinery, Ministry of Education, Shanghai 201620, China
3. College of Mechanical Engineering, Donghua University, Shanghai 201620, China
4. School of Mechanical Engineering, Tiangong University, Tianjin 300387, China

Abstract: Industrial textile materials are a new type of basic functional or structural material produced by weaving, knitting, or non-weaving of fibrous materials. They have been widely applied in the fields of aerospace, national defense, ocean engineering, energy, environmental protection, transportation, and civil construction. The rapid development of industrial textile materials can significantly promote China's manufacturing industry, transform and upgrade China's textile industry into an emerging resource industry, and contribute to the dual international and domestic circulation of China's textile industry. In this study, we analyzed the development status, application scenarios, industrial demand, and manufacturing technologies of industrial textile materials, clarified the development direction and focus of relevant technologies and equipment, and proposed countermeasures. China must formulate specific policies to coordinate technological research, equipment development, production, and application of the industry, establish a standards system for industrial textile equipment, and develop strategies for innovative services and talent training.
Keywords: industrial textile material; new basic material; textile industry; manufacturing technology

1 Introduction

The global textile industry is at a critical stage in the evolution of business forms and the upgrade of economic development models. Although developed countries have placed the growth of the traditional textile industry in developing countries with lower comprehensive costs, they attach great importance to the development of textile materials, technology, and equipment applied in the industry, and support it as an essential aspect of the future of the manufacturing industry. The United States introduced the new concept of revolutionary fibers and fabrics [1]. An innovation platform was established by the United States Department of Defense to develop traditional textiles into intelligent textiles with various functions, thus laying a foundation for the future technological leadership of the United States in complex fibers and functional fabrics. Germany put forward the concept of future textiles [2], believing that textiles will no longer be a traditional industry in the future but a brand-new product and service industry that is created based on new materials, intelligent products, energy conservation, and environmental protection.

Under the new international situation and domestic development background, the China Textile Machinery

Received date: December 15, 2021; **Revised date:** February 25, 2022
Corresponding author: Chen Ge, Professor at Donghua University. The main research direction is new textile machinery and mechatronics. E-mail: chenge@dhu.edu.cn
Chinese version: Strategic Study of CAE 2022, 24 (2):123–131
Cited item: Hou Xi et al. Industrial Textile Materials in China: Development Status, Demand and Countermeasure. *Strategic Study of CAE*, https://doi.org/10.15302/J-SSCAE-2022.02.019

Association proposed a new concept for industrial textile materials, focusing on an essential part of industrial textiles: the basic materials in the industrial field, aiming to guide China's manufacturing industry with a new understanding of the textile industry and focusing on the new direction of textile industry development. Industrial textile materials represent a new type of basic functional or structural material produced from knitted, woven, or nonwoven raw fibers. They have been widely applied in the fields of aerospace, national defense, ocean engineering, energy and environment, transportation, civil construction, and pipeline conveyance. The rapid development of core technology and equipment for producing industrial fabrics is expected to help China occupy a new commanding position in the manufacturing industry and turn into a strategic initiative the soonest possible. This should facilitate the reconstruction of China's industrial raw material industry, boost the updating of materials in many fields, reduce the import, mining, and processing of metal ore raw materials, and contribute to the early realization of China's carbon peaking and carbon neutralization goals. It is also expected to transform and upgrade China's textile industry into an emerging resource for modern industry, which is of great significance to the international and domestic double cycle of China's textile industry.

Owing to the widespread application of industrial textile materials, the production, processing, and application of industrial textile materials do not have the upstream and downstream relationships of the traditional textile industry chain and lack chained breakthroughs regarding key technologies, which restricts the production scale and application of industrial textile materials. Processing enterprises are relatively closed and technologically blocked, which leads to the dilemma of small enterprises' inability and large enterprises' reluctance to invest in the research and development (R&D) of equipment technology. Spontaneous collaborative innovation among various specialties and industries is a challenge. The relevant standards for equipment and products have not been unified, and there is no effective relationship between existing standards. Most textile materials industries in China are small- and medium-sized enterprises with weak technological innovation abilities. There is no technological innovation service platform, particularly for industrial textile material enterprises. There is a severe shortage of specialists, especially high-level specialists, and there is no specific training system or program in higher engineering education.

2 State of the art of industrial textile materials

The development of technologies and equipment for industrial textile materials is still in its early stages. The broad application prospects of industrial textile materials in the civil field in China can lead to the rapid development of industrial textile materials and lay a solid foundation for the development of aerospace, national defense, and military industries. The following is an introduction to the development of industrial textile materials in China and abroad, produced from woven, knitted, and non-woven fibers.

2.1 Woven industrial textile material

Woven industrial textile materials include flat woven, multilayer woven, and three-dimensional (3D) woven fabrics, such as single-layer carbon fiber, double-layer hollow, angle-interlock structure, and tubular woven fabrics.

The main manufacturers in other countries are Toray, Tenax, Forrisio, Biteam AB, and 3TEX. The products are mainly used in the aerospace, automobile, medical equipment, and transportation fields.

The leading manufacturers in China are Nanjing Glass Fiber Research Institute, Tianniao Company, Weihai Tuozhan Fiber Co., Ltd., Jilin Shenzhou Carbon Fiber Co., Ltd., and Sichuan Xinwanxing Carbon Fiber Composites Co., Ltd. The products are mainly used in aerospace, railway transportation, new energy resources, engineering vehicles, naval architecture, marine engineering, and concrete structure reinforcement. The 3D weaving equipment developed by Zhejiang Sci-Tech University can be used to weave 3D orthogonal, 3D angular interlocking, and 3D layer-to-layer fabrics and realize a continuous change in the thickness of full-plane fabrics. These products can be applied to high-performance blade components, surgical implants, and spatial structures. Currently, China has developed a variety of 3D woven materials. These products are used in the Chinese aerospace industry.

2.2 Knitted industrial textile material

Knitted industrial textile materials include axial warp-knitting, 3D interspace warp-knitting, mesh-warp-knitting, and weft-knitting structural materials.

Equipment manufacturers in other countries include Karl Mayer and Liba from Germany, whose equipment is primarily used for wind power generation, bridge construction, aerospace, vehicle, and ship manufacturing [3]. As early as the 1980s, warp-knitted axial composite materials were used by Owens Corning, Hexcel, and Milliken in aerospace engineering [4]. In 2007, warp-knitted biaxial fabric was used in lightweight composite bridges in Copton,

DOI 10.15302/J-SSCAE-2022.02.019

Germany. The weight of the bridge body was reduced by two-thirds [5].

Chinese manufacturers include PGTEX, Changzhou Runyuan Warp Knitting Machinery Co., Ltd., and Fujian Xingang Textile Machinery Co., Ltd. [6], whose products are widely used in wind power generation, building materials, and railway transportation [7]. Weft woven axial fabrics are often used in wind turbine blades, reinforced concrete materials, and bulletproof equipment. Warp-knitted mesh structure materials are mainly used for making safety nets, reinforcement nets, and flame-retardant protective nets. In addition to the application of high-performance fibers in knitted axial fabrics, metal fiber materials have also been applied, for example, the warp-knitted net of nickel wire used for satellite antennas, pure alloy lead fiber used as the core, and external chemical fiber used for soft lead screens and protective clothing against nuclear radiation [6]. Warp-knitting geogrids have also been used in major projects. For example, the key project of Zhejiang Province, the Ningbo Daxie Island Bridge, used more than 2×10^4 m^2 of domestic high-strength polyester warp-knitting geogrid to overcome the partial fracture of plastic grille after filling and compaction [8].

2.3 Weaving industrial textile material

Weaving industrial textile materials include two-dimensional weaving structures, 3D integrated weaving structures, and multilayer interlocking braided structures.

The leading manufacturers in other countries are 3TEX and Boeing, and the products are mainly used in fuselage panels, full-size wings, fuselage ring frames, and window frame structures. General Electric first attempted a 3D braided carbon fiber–carbon composite for rocket engine components, which reduced its weight by 30% to 50% [9]. Braided structural fabrics are used in many vital components of structures such as Voyager, Starship, and V-22 Osprey. They are also used in the export cone, nozzle, and shell connector of a solid rocket engine in France [10].

The production enterprises in China are mainly Jiangsu Gaobei Intelligent Equipment Co., Ltd., Xuzhou Henghui Weaving Machinery Co., Ltd., 3DBraiding, and Yangzhou Jushen Rope Cable Co., Ltd., whose products are mainly used in transportation, engine housing [11], railway locomotive parts, aircraft brake prefabricated parts, satellite parts, carrier rocket housing, radar, and radome [10]. Donghua University has processed a high-precision 3D spherical 3D weaving machine for the prefabricated body of the torch shell of the 2022 Beijing Winter Olympics, while Tiangong University used 3D integral structure materials for engine nozzle shells [12].

2.4 Non-woven industrial textile material

Non-woven industrial textile materials mainly include non-woven fabrics and direct molding of fibers and resins.

Foreign manufacturers include DuPont, Berry, and Spinnbau [13]. These products are primarily used in the medical health industry, building materials, geotechnical composites, and environmental filtration.

The leading manufacturers in China are Taian Road Engineering Materials Co., Ltd., Huayang New Materials, TianDingFeng Holdings Co., Ltd., and Shandong Province Winson Non-woven Materials Co., Ltd. These products are mainly used for civil reinforcement, building waterproofing, membrane structure materials, and protective materials. For example, spunbond-needled geotextiles can be used for airports, railways, highways, and other infrastructure construction, and tubular polyester-ramie/epoxy non-woven composites are strong enough to be relined to repair drainage or sewage requirements for pipeline working pressure [14].

3 Manufacturing technologies of industrial textile material

3.1 Industrial textile materials of woven

3.3.1 Single-layer woven

Single-layer woven-structured textile materials mainly include glass fiber cloth, carbon fiber cloth, geotextile, and flat cable ducks. From the perspective of the woven principle, traditional looms can process single-layer woven structure textile materials; however, most devices used in practical production are rapier looms, carrier looms, and circular looms.

The widths of geotextiles produced by the rapier looms and water-jet looms in China can reach 3.8 m and 3.6 m, respectively. A domestic carrier loom is used to produce high-strength and low-elongation woven geotextiles with a width of 7.4 m, which helps overcome the width limitations of domestic woven geotextiles. The circular loom can produce geotextiles that have the characteristics of high gram weight, high tensile strength, and large width. Rapier looms and carrier looms are generally used in the production of wide-flat cable ducks. Carbon fiber cloths and glass fiber cloths are typically processed using rapier looms.

Low-gram weight carbon fiber looms use unfolded carbon fiber tows as warps and wefts and weave them into flaky fabrics according to specific rules. Compared to traditional carbon fiber fabrics, the fiber volume content of low-gram weight carbon fiber fabric is higher, the weight is lower, the buckling degree of fibers in the fabric is low, the gap ratio is low, and the surface of the fabric is smooth. Therefore, the mechanical properties of the composite materials can be improved.

3.1.2 Double-layer woven

The double-layer rapier loom includes five systems: warp let-off, opening, weft insertion, beating-up, and coiling, and a cutting device that can weave continuous fibers into a fabric with an integrated structure and function. The upper and lower layers and z-direction fibers constitute a hollow fabric with a sandwich structure. If it is cut using a cutting device, pile fabric can be formed. This hollow woven fabric with a sandwich structure has the characteristics of close texture, special wear resistance and nonskid properties, strong lodging resistance, and diverse styles. It is used in interior decoration, carpets, and other civil products, and is increasingly used in industrial products.

3.1.3 Three-dimensional woven

Three-dimensional weaving technology enables fibers to be distributed in multiple directions and interweave, affording the overall structure of nonlayered woven textile materials, which has the advantages of light weight and excellent mechanical properties [15]. The key technologies mainly include the expansion of fabric thickness and realization of multi-sheds, realization of parallel beating-up, different opening amplitudes, and compensation of warp tension.

3.1.4 Circular woven

Circular looms include open-type nose plates, cams, and electromagnetism. Circular looms of open-type nose plates are primarily used to produce large-density tubular fabrics such as fire hoses and siphons. The circular looms of the open cam are used to weave geotextiles such as woven bags. These two types of circular looms can only produce single-layer tubular fabrics that require high wear resistance of the yarns. Circular looms of the open-type electromagnetism can be used to produce multilayer 3D tubular fabrics. The principle is to use the cam and electromagnetic needle selector to work together to realize a warp opening. The cam is only used as the lifting part of the heddle. The electromagnet selects a heddle according to the requirements of the fabric structure. The heddle at the upper and lower positions controls the warp to form openings that can produce multilayer orthogonal tubular 3D fabrics and angle-interlock tubular 3D fabrics.

3.2 Industrial textile materials for knitting

3.2.1 Axial warp knitting

Three main types of axial warp knitting exist. A uniaxial warp-knitting structure is generally produced by a weft insertion Raschel machine, and its structure has good fiber continuity and linearity. A high-performance twistless yarn is generally selected as the interlining of the biaxial warp-knitting structure [16], and the fabric is designed as a dense or semi-mesh structure. A biaxial warp-knitting machine generally produces it, and it can also be bonded with nonwoven materials, fiber nets, films, or other materials to form composite fabrics. A multiaxial warp-knitting structure can be directly lined with parallel yarns longitudinally, laterally, or diagonally. It also includes four interlining systems and a tying system, which can process the fibers into functional integrated fabrics with the multi-angles of +30 °, +45 °, +60 °, +90 °, −30 °, −45 °, −60 °, and 0 °.

3.2.2 Three-dimensional spacing warp knitting

The warp knitting spacing structure is a kind of 3D effect warp knitting structure produced by a double-rib warp loom. Spacing fabric can be applied to cushion materials, has good resilience, air permeability, and heat permeability, is easy to wash and dry, and can be used for mattresses, seat cushions, sleeping cushions, bathtub cushions, and motorcycle seat cushions. The stiffness and strength of self-setting concrete reinforced with mesh warp-knitting-spacing textile materials can be significantly increased. They can form areas with varying degrees of elasticity, air permeability, wear resistance, and stiffness when used in shoe materials. Warp-knitting spacing textile materials can be easily embedded with electrode materials to produce various smart textiles. The surface of the warp-knitting spacing textile materials is compounded with rubber and then filled with high-pressure gas to form an inflatable board with a certain hardness and a smooth surface. The special negative Poisson’s ratio of warp-knitting spacing textile materials with energy absorption and impact resistance is suitable for use in the field of protective materials, such as bulletproof, stab-proof, and engineering protection.

DOI 10.15302/J-SSCAE-2022.02.019

3.2.3 Mesh texture warp knitting

In the field of construction, safety nets, enhancement networks, and flame-retardant protective nets are mesh-textured warp-knitting fabrics. The single-bed warp knitting Raschel machine produces flat guard nets to meet application requirements with a low safety factor. The double-rib warp loom produces guard nets with cylindrical net knots to satisfy the corresponding high safety factor application requirements.

In the field of biomedical instruments, warp-knitting mesh textures such as hernia repair mesh, soft tissue repair mesh, vascular stent, and heart valves are widely used and are characterized by high adhesion, controllable water permeability, controllable ductility, and compressibility.

In the aerospace field, the warp-knitting mesh texture is mainly used for battery substrate materials and satellite metal antenna networks because of its lightweight, stable, and diverse structure.

3.2.4 Three-dimensional forming warp knitting

The combination of the organizational structure and warp-knitting process completes the 3D structure formation of different shapes. The warp-knitting structure is anti-separation, and its fabric can maintain a high structural stability and mechanical properties when damaged.

The 3D forming structure of precision warp knitting into a seamless state is mainly used for special medical materials such as artificial blood vessels, medical shorts, and gauze fixing nets. The military camouflage network formed by integral warp knitting is primarily used in the field of national defense. The key to this lies in the stability and durability of the structure. Polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET), and other raw materials are mainly used in the production of artificial turf through integral warp-knitting technology, which has the characteristics of short processing time, high efficiency, and environmental protection.

3.2.5 Weft knitting

Weft knitting refers to the formation of a stable structure by bending yarns in the transverse direction into loops and interlocking them. It includes single circular, double-sided, and axial weft knitting. As weft-knitted fabric is reinforced, it has the following advantages: first, it has good ductility and flexibility and is suitable for processing resin transfer molding composites; second, the structure is evenly distributed, and the fiber orientation is stable, which can avoid the flake structure and delamination easily formed in laminated composites [17].

3.3 Industrial textile materials of weaving

3.3.1 Two-dimensional weaving

Two-dimensional weaving originated from the ancient method of hand-woven ropes. During the weaving process, multiple yarns move in different directions, interlacing and winding in the direction of the fabric, forming a flat or stringy fabric. For example, two-dimensional rotary weaving includes rope and maypole weavings [18].

3.3.2 Three-dimensional weaving

(1) Track and column 3D weaving.

The yarn carrier is moved by the tracks on the chassis of the weaving machine so that the yarns are interwoven to form a fabric. The yarn carrier array in the chassis structure returns to its initial shape after four moves [18], which is called four-step weaving. After process adjustment, there are eight-step and two-step weavings.

(2) Rotary 3D weaving.

It can be used to weave 3D preforms with special cross-sections, such as L-shaped weaving. The dial-plate mechanism on the chassis of the 3D rotary weaving machine is replaced by a horn ring mechanism, which drives the yarn carrier to interweave the yarns to form 3D fabrics.

(3) Hexagonal 3D weaving.

The basic configuration of a hexagonal 3D weaving machine is a horn-ring wheel with six-toothed wings. The gap between the horn ring and the adjacent ring is formed into an entire circle. A single horn ring can accommodate two or more yarn carriers. The weaving chassis containing a hexagonal horn ring can accommodate approximately 38% more yarn carriers than a rotary 3D weaving machine with the same area [18]. Additionally, the principle of quadrilateral 3D weaving is similar to that of hexagonal 3D weaving.

3.4 Industrial non-woven textile material

Non-woven manufacturing technology is generally classified according to the web forming method, reinforcement method, and structure and type of fiber mesh. According to the processing route, it is divided into web forming and reinforcement methods. The methods of web forming are dry-laid web, wet-laid web, and polymer extrusion web forming. Reinforcement methods include mechanical reinforcement, chemical bonding, and thermal bonding. A combination of different process variations and processing methods can produce products with various specifications and structures.

Direct fiber and resin mixing molding includes fiber lamination, fiber winding, fiber pultrusion, and short-cut fiber–resin mixed injection. Pre-impregnation is a critical step in this type of molding process, which can improve the mechanical properties of fibers. The subsequent processes include compression molding, resin injection molding, winding molding, and pultrusion molding. Compression molding involves preheating the prepreg to be molded and then applying a certain pressure to form the desired shape of the product, which can yield profiles with different shapes and cross-sections and composite materials with high fiber content, excellent performance, and low cost [19].

The R&D of industrial textile materials manufacturing technology and equipment is China's focus. It mainly involves the automatic forming technology and equipment of high-density and complex structural prefabricated parts, the automatic forming process of lightweight skeletons, and intelligent equipment, which can satisfy domestic aerospace, marine engineering, construction transportation, new energy, and other fields. Relevant domestic enterprises have research and processing capacities for industrial textile materials. China is at the same stage as the advanced international level in 3D weaving technology and equipment. However, there is still a gap between domestic equipment and advanced foreign equipment regarding reliability and product adaptability.

4 Key applications and demands of industrial textile materials

4.1 Civil construction

Owing to the corrosion resistance of steel bars, old reinforced concrete buildings that have been in use for a long time must be strengthened and transformed. The specific implementation plan for renovating old buildings is to reconstruct or reinforce above-ground structures and replace reinforced concrete with composite materials based on industrial textile materials (such as carbon fiber reinforced concrete and fiber woven mesh reinforced concrete). According to statistics, as of May 2019, 170 000 communities had to be renovated [20], with an investment of more than 4 trillion CNY.

The production energy consumption of industrial textiles is significantly lower than that of traditional steel profiles, and the mechanical properties of profiles based on industrial textiles are also significantly improved compared to those of traditional steel profiles and traditional pultruded profiles. Currently, the energy consumption per ton of fiberglass yarn production in China is 0.35 tce [21], while the comprehensive energy consumption per ton of steel production of crude steel is 0.551 tce [22]. The production energy consumption comparison is presented in Table 1, taking a round pipe profile (outer diameter of 180 mm, inner diameter of 160 mm, and length of 6000 mm) as an example. Overall, the energy consumption of the braided pultruded glass fiber profiles and braided pultruded carbon fiber profiles is significantly lower, and the mechanical properties are better than those of the steel profiles.

Table 1. Comparison of energy consumption and performance of fiber reinforced composite profile and steel profile equipment.

Profile type	Equipment energy consumption per unit mass A_i/kgce (1 t)	Same volume equipment energy consumption B_i/kgce	Maximum axial tensile force F_i/N	Maximum bending torque M_i/(N·m)
Steel profiles	26.80	26.80	2.14×10^6	8.60×10^4
Traditional pultruded fiberglass profiles	15.52	4.18	1.50×10^6	6.02×10^4
Braided pultruded fiberglass profiles	14.39	3.69	2.41×10^6	9.68×10^4
Braided pultruded carbon fiber profiles	17.27	3.54	6.42×10^6	25.8×10^4

4.2 Bridge and tunnel engineering

According to relevant data from the transportation industry, 7256 dangerous old highway bridges have been rebuilt in China from January to October 2021 [23]. There are 851 500 highway bridges in China; the total length is 2.269×10^7 m, the annual growth rate is more than 10 000, and the defects of highway bridges in urgent need of repair account for 40% [24]. Using carbon fiber composite cables instead of steel cables can also be used for cable-stayed or suspension bridges, which are nearly 85% lighter than the cable, while their tensile strength is seven times that of

DOI 10.15302/J-SSCAE-2022.02.019

the cable. Although the cost per unit mass of carbon fiber cables is higher than that of steel cables, in the long span of 2500 m and above, carbon fiber cables exhibit superior performance and can realize cable and anchor integration with a 100% anchoring rate and higher cost performance [25].

4.3 Pipeline transportation

Thermoplastic wear-resistant materials can be used to repair old steel pipes. Owing to the sharp decrease in oil and natural gas resources on land and in the shallow seas in China, the exploration of offshore oil and gas fields has gradually moved toward the deep-sea area of 1500–3000 m. Traditional steel tubing is no longer suitable owing to high-pressure loads and increased installation and transportation costs, and fiber composite pipes (carbon fiber/glass fiber reinforced composite material as matrix) are gradually being used. The service life of carbon fiber composite pipes can be doubled, and the average annual cost can be reduced by approximately 40% when using carbon fiber composite pipes as an example, compared with seamless steel pipes from an economic point of view, which promotes the gradual realization of full non-metallization of pipes for deep-sea transportation [26].

4.4 Transportation

Strengthening ballastless track boards with basalt fiber composite material can improve insulation performance by 59%–74%, which can ensure the transmission performance of track circuits and the safety of train operation [27]. In addition, glass fiber reinforcement is used instead of steel bars for super-large-diameter mud shields. For example, during the construction of Shantou Suai Passage, the shield section of the submarine tunnel with a length of about 3047.5 m and a diameter of about 15 m was completed by the construction method of glass fiberboard and one-sided glass fiber reinforcement [28]. On August 31, 2021, the first batch of 18 Red Boat carbon fiber new-energy buses officially landed in Jiaxing, Zhejiang Province. The body of the vehicle is made of aviation carbon fiber composite materials. Compared with traditional metal materials, the vehicle strength is improved by approximately 10%, the mass is reduced by approximately 30%, and the energy consumption is reduced by approximately 15% [29].

4.5 Marine engineering

Marine engineering cables are typically used in resource development and equipment construction such as mooring, anchoring, towing, and lifting [29]. Traditional multipurpose steel cables are gradually being replaced by fiber cables because fiber composite ropes can be used in deep-water wells at depths of 3000 m, compared with steel ropes at depths of 1500 m. In 2020, the China National Offshore Oil Corporation adopted domestic polyester cable as a fixed cable for the semi-submersible platform for the first time, with a diving depth of 1500 m in the South China Sea [26].

4.6 Other application fields

In addition to the above application scenarios, industrial textile materials are widely used in national strategic fields and essential areas for people’s livelihoods. Industrial textile materials are the “skeleton” of composite materials, and their new molding methods are opening up broader market prospects for the application and processing of composite materials. Whether it is the strategic development needs of aviation, aerospace, national defense, and military industries, or the commitment to carbon peak and carbon neutrality, it is the general trend of industrial textile materials to replace steel.

5 Development direction and path of industrial textile materials technology and equipment

5.1 Development direction

5.1.1 Woven

This section focuses on the development of a honeycomb fabric loom, flat multiaxial loom, double rapier loom, complete sets of equipment for producing low-gram and heavy-carbon fiber fabrics, and woven technology and equipment to produce 3D hollow textile materials. They can process high-performance fibers into double-layer and multilayer fabrics with spacing, which can be used in high-speed train shells, aviation composite floors, lightweight profiles, high-strength inflatable fabrics, and lightweight sound insulation building materials.

5.1.2 Knitting

This section focuses on the development of technical equipment for multiaxial weft knitting and circular warp knitting, circular knitting machines with weft spacing fabric with linings, and multiaxial warp-knitting machines. Through this technical equipment, the fibers are processed into functional integrated fabrics with multi-angle ply, which are applied to netting materials and filter membranes for marine engineering. Therefore, it is necessary to focus on developing warp-knitting equipment for super-thick, high-strength, and heavy-duty inflatable fabrics. The fabrics produced by the space mesh double-layer weaving technology can be processed into composite inflatable fabrics.

5.1.3 Weaving

This section focuses on the development of high-performance cable-weaving equipment that can be applied to cables, cable-stayed bridges, or suspension bridges for marine engineering. This also centers on developing special weaving technology and equipment for producing variable-cross-section gyro rotors, variable-diameter weaving bodies, and tubular 3D fabrics of high-performance fibers, which can be applied to the parts and components of missiles and spacecraft.

5.1.4 Non-woven

This section focuses on the development of forming technologies and equipment for high-performance short-fiber preforms. High-performance fibers such as carbon, quartz, and metal fibers are made into various preforms through cut-out, carding, web-lapping, web forming, and fixed-line processes, and then made into different products through subsequent processes using this technology and equipment. These products can be used in brake pads, energy storage flywheels, felt pads, thermal insulation materials, aerospace, military, and other applications.

This section also focuses on the development of pultrusion forming technology and equipment for the section bar of the fiber composite. High-performance fiber filaments or short fibers are combined with resin through the pultrusion forming process to form the section bar of fiber composites, which can form various shapes such as irregular sections, have excellent characteristics such as light weight and high strength, and can replace some steel and non-ferrous metal profiles in many fields.

5.2 Development path

Industrial textile materials have been applied in the fields of textile engineering, materials, electromechanics, and information technology, with obvious interdisciplinary characteristics. Its development follows the law of "one generation of materials, one generation of technology, and one generation of equipment".

The specific development path involves studying the interactions among fibers, fiber polymers, textile materials, and mechanical systems in the process of forming industrial fabric and reveals the connotation and core problems, such as the formation mechanism, coupling mechanism, and force field behavior of industrial fabrics. It is also necessary to ensure the continuous development of core industrial textile material varieties and to fill the gap in high-end industrial textile materials.

Based on the structural shapes and mechanical property index values of industrial textile materials, the forming method and process route of industrial textile materials are developed, the buckling deformation and force field change in the formation process of industrial textile materials are focused on, and the effects of different forming methods on various performance indices of industrial fabrics are compared. A production process system between fiber, machinery, and industrial textile materials has been established to effectively control the structure and performance indices of industrial textile materials.

By using existing textile equipment and its advanced manufacturing technology and integrating advanced technologies such as textile and information technologies, a high-end industrial textile equipment R&D system that integrates digital design and manufacturing, intelligent control technology, and the weaving process expert system can be constructed to independently develop and industrialize the automatic, digital, networked, and intelligent high-end equipment for industrial textile materials.

Based on the advanced intelligent manufacturing system and high-end equipment of industrial textile materials and by optimizing the intelligent production line of industrial textile materials, an entire-process intelligent manufacturing standardization system for industrial textile materials, including equipment, processes, and products can be constructed. The characteristic data of the equipment, processes, and products can be provided for the intelligent manufacturing of industrial textile materials.

DOI 10.15302/J-SSCAE-2022.02.019

6 Countermeasures and suggestions

6.1 Strengthening policy support for the industrial application of industrial textile materials

First, China must formulate special policies to support the coordination and development of the industrial chain (i.e., technology R&D, equipment development, textile processing, and textile application) of the industrial textile material industry. For this, China must strengthen cross-agency and cross-industry coordination and communication in building materials, medical treatment, rail transit, and automobiles; improve systematic procurement channels; formulate policies in terms of environmental protection, consumption reduction, and energy conservation; and encourage and support independent brands of industrial textile products and production equipment to participate in procurement competition.

Second, China should set up special projects to promote the application of industrial textile materials in green manufacturing, high-performance manufacturing, and key new materials. Demonstration and pilot construction should be conducted, including the design, production, application, standards, safety, and manufacturing of industrial textile materials.

6.2 Strengthening joint efforts on industrial textile materials technology and equipment

First, through major national projects, industrial textile materials manufacturing enterprises, universities, and research institutes should be guided to organize joint efforts to make breakthroughs in key technologies associated with high-performance industrial textile materials equipment, and capable enterprises should be supported to form demonstration applications and reach advanced international levels.

The second step is to establish a cloud platform for manufacturing industrial textile materials in textile industrial agglomeration areas. Central and local governments, together with relevant professional associations, should cultivate and build a cloud platform for industrial textile material manufacturing enterprises with good basic conditions in industrial fabric industrial agglomeration areas, thus providing support for the collaborative design and manufacturing of industrial textile materials.

6.3 Establishing a sound standards system for industrial textile materials and equipment

First, the industrial textile materials industry requires an overall standards system, and detection standards and identification systems must be established and improved for industrial textile material technologies and equipment. Government departments should issue policies to regulate the functional testing of existing industrial textile materials and equipment, establish and improve the relevant standards system for emerging industrial textile products, improve the overall level of standards, solve the problem of the lack and lag of emerging industrial fabric product standards, and create conditions for improving the quality of emerging industrial fabric products.

The second is to promote the coordination and internationalization of standards between the upstream and downstream industrial fabric industry chains. Government departments should issue relevant policies to guide the connection between industrial textile materials and downstream fields, such as medical treatment and construction, and promote the general basic standards and method standards of industrial textile materials in line with international standards.

6.4 Cultivating innovative service system in the field of industrial textile materials

First, in textile industry agglomeration areas, technical intermediary service institutions related to industry chain technology should be created and improved. Government departments, industry associations, and the market should collaborate to establish technology intermediary service organizations that feature a specific scale, specialization, and operation standardization, gather a staff team with high professional quality, and provide small- and medium-sized textile enterprises related to technical consulting services and achievement transformation.

Thus, the linkage between generic technology and application research on industrial textile materials should be promoted. The government departments in charge shall increase the input and supply of R&D for key common technologies of industrial textile materials with policy support. Government procurement should promote the transfer of common key technologies in the industrial textile industry and the independent innovation of small- and medium-sized industrial textile enterprises.

6.5 Strengthening the construction of talents in the field of industrial textile materials

First, it is suggested that competent departments of industry education guide and strengthen the construction of professional and technical personnel and technical training in the field of industrial textile materials. Universities and enterprises should jointly train technical personnel customized for the textile material industry. A mechanism should be established jointly by universities, higher and secondary vocational schools, and enterprises to cultivate applied talent for the industrial textile material industry. Practical training bases should be constructed based on production, education, research, and application integration to cultivate technical personnel in the industry.

The second suggestion is to vigorously cultivate model representatives of technology in the field of industrial textile materials by relying on major science and technology research projects, key disciplines, and cooperation projects of scientific research bases. The construction of a talented team should be considered as an important assessment index, and innovation teams should be actively built.

The third goal is to strengthen the training of composite-applied talent in the field of industrial textile materials. Colleges and universities should improve the training program of the relevant courses in industrial textile materials; strengthen the interdisciplinary integration of textiles and materials, machinery, information, computers, and related application fields; and train graduate students with professional degrees in the field of composite industrial textile materials. Additionally, they should improve the undergraduate courses of related courses, strengthen engineering practices, and cultivate engineering talent with strong synthesis abilities.

References

[1] The United States established an innovation institute for fiber and fabric manufacturing [J]. Textile Inspection and Standard, 2016, 2(2): 50–51. Chinese.

[2] Ge Y. Study on futureTEX project in Germany [J]. International Textile Review, 2017, 45(10): 4–6. Chinese.

[3] Gries T, Raina M, Quadflieg T, et al. Manufacturi ng of textiles for civil engineering applications [J]. Textile Fibre Composite in Civil Engineering, 2016: 3–24.

[4] Liu L L, Kang Y, Luo M, et al. Research progress of technical knitted structural materials [J]. Textile Review, 2021 (5): 70–74. Chinese.

[5] Ye Q, Miao X H, Jiang G M. Application of warp knitted axial fabric on reinforced concrete [J]. Industrial Textiles, 2011, 29(4): 27–31. Chinese.

[6] Wan A L, Cong H L, Jiang G M, et al. Application of knitting technology in industrial textile [J]. Textile Review, 2014 (7): 28–32. Chinese.

[7] Qi F. Application of knitting technology in industrial textile field [J]. Textile Report, 2019 (5): 10–11. Chinese.

[8] Wang X H. Development and application of warp knitting geogrids in China [J]. Industrial Textiles, 2000 (2): 5–7.

[9] Wang X M, Xing Y F. Research progress of three–dimensional braided composite materials [J]. Acta Aeronautica et Astronautica Sinica, 2010, 31(5): 914–927. Chinese.

[10] Hao X C, Hu J. Application of 3D weaving technology in aerospace [J]. China Science and Technology Information, 2019 (21): 25–26. Chinese.

[11] Jiang J H, Chen N L, Qian X M， et al. Advanced base materials for industrial textiles: Progress and countermeasures [J]. Strategic Study of CAE, 2020, 22(5): 51–59. Chinese.

[12] Chen L, Zhao S B, Wang X M. Development and application of 3D textile reinforcements in the aerospace field [J]. Textile Review 2018 (S1): 80–87. Chinese.

[13] Xiang Y. The Technological progress of non-wovens and the gap between domestic and foreign countries [J]. Industrial Textiles, 2005 (5): 1–8. Chinese.

[14] Zhang S J, Fu L S, Wang R, et al. Thickness design of polyester ramie non-woven/epoxy composite for pipeline repair [J]. Journal of Composite Materials, 2019, 36(12): 2805–2814. Chinese.

[15] Nie J B. Development and properties of angle interlocking fabric [D]. Suzhou: Soochow University(Master's thesis), 2007. Chinese.

[16] Wei G Q, Jiang G M, Miao X H. The application and outlook of the multiaxial warp-knitted fabrics [J]. Textile Review, 2008 (3): 70–72. Chinese.

[17] Dai Q C. Fabrication and mechanical properties of weft knitted structure Reinforced Composites [D]. Shanghai: Donghua University(Doctoral dissertation), 2007. Chinese.

[18] Li Z N. Study on forming principle of hexagonal braided three– dimensional fabric and properties of composite materials [D]. Shanghai: Donghua University(Doctoral dissertation), 2019. Chinese.

[19] Fang L. Study on preparation and properties of continuous fiber reinforced thermoplastic composites [D]. Shanghai: East China University of Science and Technology(Doctoral dissertation), 2012. Chinese.

DOI 10.15302/J-SSCAE-2022.02.019

[20] Guidance on comprehensively promoting the reconstruction of old residential areas in cities and towns [J]. Shanghai Building Materials, 2020 (4): 1–4. Chinese.

[21] China Fiberglass Industry Association. Development plan of glass fiber industry in the 14th Five-year Plan [EB/OL]. (2021-09-08) [2021-12-10]. http:// www.cfia.x in/page64? article_id= 1838. Chinese.

[22] Experience sharing of "Leaders" of energy efficiency in key energy using industries in 2020: Energy efficiency in steel industry [J]. Metallurgical Automation, 201, 45(2): 36. Chinese.

[23] China Transportation News Network. In the first 10 months, 7256 dilapidated highway bridges were renovated nationwide [EB/OL]. (2021-11-11)[2021-12-10]. http: //www. gov. cn/ xinwen/2021–11/11/content_5650291. htm. Chinese.

[24] Wang H L, Chang C W, Yang X L, et al. Application prospect of Basalt Fiber in bridge engineering and problems to be solved [J]. Railway Construction, 2011 (9): 15–17. Chinese.

[25] Zhang Z T, Wu T, Fang Z. Wind resistance analysis of long–span cable-stayed bridge based on high performance materials [J]. Journal of Hunan University(Natural Science), 2018, 45(5): 11–18. Chinese.

[26] Zhou X Y, Li J R, Pei F. Application of carbon fiber composite in deepsea oil and gas field [J]. Fiber Composites, 2018, 35(1): 10–14. Chinese.

[27] Yang Y. Study on the basic performance of a new type of ballastless track plate reinforced by fiber composite reinforcement [D]. Nanjing: Southeast University(Doctoral dissertation), 2016. Chinese.

[28] Wang D L. Application analysis of glass fiber reinforcement in subway shield construction [J]. Equipment Management and Maintenance, 2021 (2): 141–142. Chinese.

[29] Song B T, Jiang R X, Li T. Application and development status of synthetic fiber cable for offshore engineering [J]. Textile Review, 2021 (1): 76–79. Chinese.