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Development Strategies for China's Advanced Fiber Materials Industry

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Abstract: The chemical fiber volume of China is ranked first worldwide and constitutes an essential industry of the national economy. However, regarding the development of the chemical fiber industry, several significant challenges remain. In addition, the promotion of advanced fundamental fiber materials has become the crucial to the high-quality development of the chemical fiber and textile industries. This study focuses on three types of advanced fiber materials: differential, high-performance, and bio-based fibers. The statuses, challenges, and developmental trends of advanced fiber materials in China are analyzed. On this backdrop, we summarize the key tasks required in the future development of advanced fiber materials, including the development of technologies to form representative products, improvement of intelligent manufacturing, strengthening of the independent innovation capacity, and enhanced training of scientific and technological talents. Furthermore, , with the objective of providing a theoretical reference for the high-quality development of fiber materials in the Chinese fiber industry, this study provides suggestions regarding the industrial development strategy, scientific and technological innovation systems, role of science and technology, internationalization of important enterprises, and coordinated development.

Keywords: differential fiber; high-performance fiber; bio-based fiber; industry development

1 Introduction

Owing to its production, consumption, and exportation capabilities, China possesses a complete industrial chain of chemical fibers with rich variations, and offers the largest product scales with full industrial support. Chemical fiber products can be applied in the conventional fields of textile, clothing, household, and other consumer goods, as well as in transportation, environmental protection, safety protection, geotechnical construction, medical and health, aviation, aerospace, national defense, and military industries [1]. With the rapid development of the Chinese chemical fiber industry at the end of the 20th century owing to the continuous breakthroughs in polyester fiber localization technologies and equipment, production cost significantly reduced while production capacity increased rapidly. In 2019, the domestic chemical fiber yield was approximately 5.95×10^7 t, accounting for almost 80% of the global total chemical fiber output.

Presently, the industrial development of domestic chemical fiber still faces several significant challenges, such as the decrease in the additional value of products, poor market competitive advantages of high-performance fibers in terms of quality and cost, and unrealized attractive alternative of bio-based fiber fabrics for petroleum-based fiber products given the small production scale and high expense. Based on international re-specializations of textile industries, the above challenges currently limit the sustainable development of the Chinese chemical fiber industry, which makes it difficult to achieve international competitiveness.

Advanced basic fiber materials (also referred to as advanced fiber materials) are those materials with which large-scale production and wide applications can be realized. These materials exhibit one or more of the following features: good physical, mechanical properties and high quality; realization of additional functions via physical or chemical means while maintaining essential physical- and mechanical-property requirements; promotion of the greenization level for the entire

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lifecycle; improvement of manufacturing efficiency and fiber material quality via digital, flexible, and intelligent manufacturing processes, which significantly reduces the energy and material consumption.

The most important varieties of advanced fiber materials are differential functional, high-performance, and bio-based fibers. This study analyzes the developmental status, challenges, and future development trends of the Chinese advanced fiber material industry, summarizes the key tasks in future work, and presents suggestions for its development, with the objective of providing references for the development of industry and enterprises.

2 Development status of advanced fiber material industry in China

2.1 Differentiated functional fiber

In recent years, the production capacity of chemical fiber in China has continued to increase with the emergence of challenges, such as surplus production capacity. Furthermore, severe competition exists in the homogeneous varieties of conventional chemical fiber, with low additional value to the industry. Therefore, the differential and functional production of chemical fiber based on the current productivity has become crucial in the structural adjustment and industrial advancement of the chemical fiber industry.

Functional fiber is a general concept, which means that the fiber has its own specific properties and functions that endow the textile products with new properties and functions. According to their properties, functional fibers can be divided into two categories. The first category is the differentiated functional fiber, which is prepared via molecular modifications, the addition of functional components, and distinctive spinning technologies or post-treatments during the preparation of conventional chemical fiber, such as polyester fiber, polyamide fiber, and regenerated cellulose fiber. Compared to conventional chemical fibers, this type of fiber can provide significantly improved or increased properties and functions. The other type is intrinsic functional fiber, which exhibits specific properties or functions. Such fibers are prepared by the melt spinning or solution spinning of polymers with high elasticity, such as Spandex.

China has achieved remarkable progress in the development of differentiated functional fiber and has established an integral industrial chain with a complete variety of industrial systems for functional fiber. In this regard, the gap between China and developed countries and regions, such as Japan, the United States, and the European Union has been reduced significantly [2]. In 2017, the differentiated functional fiber output in China was approximately 1×10^7 t, most of which consisted of conventional functional fiber varieties with relatively low additional values, such as dope-dyed fiber, cationic dyeable fiber, high-performance polyester, and polyamide industrial yarn, and composite fiber with a low melting point. However, the proportion of functional fiber with high additional values, including super-emulation, antibacterial, flame-retardant, and far-infrared fibers, is relatively low. The production processes and technologies of differentiated functional fiber are far from mature, and the quality of the products is not sufficiently high, which limits extensive applications to high-end fabrics and products in large quantities.

2.2 High-performance fiber

The development of high-performance fiber in China has focused on carbon, aramid, ultra-high molecular weight polyethylene (UHMWPE), polyimide (PI), and polyphenylene sulfide (PPS) fibers.

2.2.1 Carbon fiber

Over the past ten years, the domestic industry for carbon fiber has gradually entered a vigorous growth period with continuous improvements in process technology, optimized process equipment, and expanding application fields. In 2019, domestic polyacrylonitrile (PAN)-based carbon fiber experienced rapid development, with yields of approximately 1.2×10^4 t. The domestic consumption exceeded 3.7×10^4 t with an increase of approximately 20% [3]. PAN fiber is used extensively in wind turbine blades, building reinforcements, pressure vessels, and other fields; furthermore, it's applied in the aviation, aerospace, electronics, and electrical fields.

2.2.2 Aramid fiber

Recently, Chinese para-aramid fiber has been developed exponentially owing to the breakthroughs in industrialization technology and the realization of batch production for several enterprises. In 2019, the domestic output of para-aramid fiber exhibited a slight increase, with a yield of approximately 2.8×10^3 t. The output of meta-aramid fiber was approximate 1.1×10^4 t [3], generally reaching the international advance level. Presently, domestic aramid products are adopted mainly in high-temperature filtration, protection, and sealing materials. Compared to imported products, domestic aramid products still lack competitiveness in high-end fields such as the aviation, aerospace, national defense, and military industries.

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2.2.3 UHMWPE fiber

The preparation technology of UHMWPE fiber in China has developed rapidly. The product quality has greatly improved; moreover, the performance index is comparable to the advanced international level, and these indices have even reached the international leading level. Overseas governments usually take measures to restrain the exportation of high-end fiber products. To date, approximately 30 domestic enterprises in China have the capacity to produce polyethylene fiber with a high strength and high modulus. The output was 2.3×10^4 t in 2019 [3] and several enterprises have a capacity of 1000 t.

2.2.4 PI fiber

Recently, the industrial development of PI fiber in China has been rapid, research in this field has attracted increasing attention from relevant scientific research institutions. PI fiber with high temperature tolerance has been commercialized in China, whereas PI fiber with a high strength and high modulus has been tested on a small scale, thus exhibiting a breaking strength and modulus of 3.5 GPa and 130 GPa, respectively, and reaching the international advanced level overall.

2.2.5 PPS fiber

The rapid development of the bag filter technology has driven the fiber-grade PPS development of resin production in domestic enterprises. The domestic yield of PPS fiber in 2019 was approximately 5.5×10^3 t [3] and most product specifications are 2.0 dtex, which are mainly used in the filter material industry. The overall demand in China remains stable. In recent years, the industrialization technology for fiber-grade PPS resin synthesis has been optimized continually and the cost has gradually been reduced. It is expected that the production will be further improved and that the market application of domestic varieties will be promoted.

2.3 Bio-based fiber

Bio-based fiber refers to polymer fiber that adopts biomass as the raw material, which contains monomers from biomass sources, or is prepared by biotechnology. It mainly comprises Lyocell fiber, polylactic acid (PLA) fiber, bio-based polyester fiber, and bio-based polyamide fiber. The development of bio-based fiber in China is still in the early stage of industrialization.

A production line with a capacity of 1.5×10^4 t/a in China Textile Academy was completed at the end of 2016. In 2019, three domestic enterprises had production lines of Lyocell fiber with a capacity of 15 000 t/a. The designed capacity of a single line was only 3.0×10^4 t/a, compared to the production capacity of 6.7×10^4 t/a for a single line of the Austrian company Lenzing. Therefore, further technical upgrades are still required.

Research on the production technology of PLA began in China in 2000. Presently, the Chinese PLA industry is in the initial stage of industrialization. Numerous domestic enterprises have constructed industrial production lines for the continuous polymerization of PLA. Furthermore, the production of filaments, staple fibers, and spun-bonded nonwovens, among others, which are mostly used in disposable sanitary materials, agriculture, clothing, and home textiles, has been realized. The development of the PLA industry has been significantly restricted owing to the lack of domestic production of the raw materials of lactide.

Since 2010, domestic enterprises have made breakthroughs in the technology for bio-based 1,3-propanediol (PDO), and the production of 10 000 t of PDO has been realized. Regarding the polymerization of poly(propylene terephthalate) (PTT), industrialization has been preliminarily realized with steady improvements of key technologies including large-scale continuous polymerization and melt spinning, which are expected to result in the stabilization, large-scale production, and application of bio-based PTT fiber in China [4].

Domestic research on polyamide 56 (PA56) fiber materials started around 2010. Cathay Biotech conducted a pilot test on bio-based 1,5-pentanediamine and PA56, which is at the advanced international level. Presently, production bases with capacities of 5×10^4 t/a for bio-based 1,5-pentanediamine and 1×10^5 t/a for bio-based PA56 are under construction in China. The development of new application fields has become the key to extensive applications.

3 Challenges of advanced fiber material industry in China

3.1 Differentiated functional fiber

The industrial development of differentiated functional fiber in China is in the early stage of rapid growth, but several crucial challenges remained. The incoordination of the research and development (R&D) between the production equipment and technologies with the current old equipment has triggered a failure to control the reaction and molding processes effectively in the production of differentiated functional fiber, which has significantly limited the development of high-quality fiber.

Another important factor restricting the development of the Chinese functional fiber industry is the lack of quality testing methods and a standards system in performance evaluation, which has resulted in a lack of norms and guidance in industrial development. The establishment of methods and a standards system for the performance evaluation and quality inspection of functional fiber is necessary to standardize the industry’s development, prevent disordered competition, and guide production enterprises to optimize the functional indicators and stabilize the product quality.

3.2 High-performance fiber

The majority of carbon fiber products in China are in the trial operation stage, and most of them are in the installation period stage; thus, the cooperation with the industry downstream still needs to be strengthened. The insufficient development of industrial application has led to a high production capacity and high operating pressure for numerous carbon fiber production enterprises. In the future, carbon fiber production enterprises in China need to strengthen the industry research linkage with the industrial application, seize market opportunities, and seek breakthroughs for the domestic development of the carbon fiber industry.

Regarding aramid fiber, the development of the meta-aramid fiber industry in China remains in the initial stage. Compared to that of developed countries, the manufacturing technology is insufficient, and it is difficult to realize the high-speed and stable production of high-performance meta-aramid products. Preliminary industrialization of para-aramid products has been realized in China. But the core technologies of certain differentiated products have not been fully achieved, such as fiber of high strength, and high model and dyeable types.

The industrial scale of UHMWPE fiber in China remains low. The production capacity in domestic single lines is generally 200 t/a, whereas it is approximately 500 t/a abroad. To improve the total production capacity, domestic production enterprises must increase their production lines, which will result in a high investment cost, low production efficiency, high energy consumption, and an increased difficulty in realizing large-scale production.

The performance of domestic PI fiber has reached the global advanced level. However, the price of PI fiber is higher than that of aramid fiber owing to the uneven quality of the products and high cost of raw materials, which limits its application in downstream enterprises. Moreover, the specification of PI fiber products in China is indigent and it is mostly produced in small batches, mainly for use in the military industry as opposed to civilian fields.

The development of domestic PPS modification technology has experienced a late start, and the majority of enterprises are small and medium sized. Furthermore, a gap exists between domestic and foreign enterprises regarding quality management and cost control of products. As foreign modified PPS enterprises have occupied the international market for a long time, domestic enterprises will encounter greater resistance in the later stages.

3.3 Bio-based fiber

The development of bio-based fiber in China remains in its initial stage, hence, the advancement gap between China and foreign countries relative to its technology, equipment, and basic research. Presently, the high production costs and weak market competitiveness of bio-based fiber restrict the development in the industry, making competition with petroleum-based fiber impossible owing to the low oil price. There is a lack of genetic, industrial microbial, and biochemical technologies to support bio-based fiber or the production of its raw materials.

Most types of bio-based fiber are in the stage of preliminary study. Certain varieties of raw materials have independent intellectual property rights, and the preparation of the fiber and raw materials is challenging and costly. In short, the gap between China and developed countries remains significant in terms of core technology, key equipment, and crucial raw materials, with a relatively low level of industrial technology.

4 Development trends of advanced fiber material industry in China

4.1 Differentiated functional fiber

High quality, multiple function, low consumption, and low emission are the development directions for the industrialization technology of differentiated functional fiber. High quality refers to low unevenness of the fiber and the stability of the fiber performance/function in textile processing, dyeing and finishing, coating, composite material processing, and applications. Multiple functions refer to the basic physical properties (such as strength, modulus, elasticity, and linear density) of fiber materials, and the performance/functions that are closely related to the improvement in the comfort, protection, and intelligence of textiles. Low consumption and low emission refer to the significant reduction in material consumption, energy consumption, harmful substance emission, waste, and waste disposal costs in the entire lifecycle of fiber material processing, including raw material acquisition, fiber manufacturing, application, and waste product recycling.

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Super-simulation fiber, low-temperature dyeing fiber, moisture absorption fast-drying fiber, and low melting point fiber are key varieties of differential functional fiber to meet the demand for a large quantity and wide range. Flame-retardant fiber, conductive fiber, antibacterial fiber, and high wear-resistant fiber are varieties of differential functional fiber that can be applied for the special requirements of combat, special protection, and intelligent textiles.

4.2 High-performance fiber

The cost reduction and high-performance enhancement of carbon fiber is a future development trend. The development of a new, cheap, alternative to carbon fiber and new processing methods aid in the reduction of production costs of carbon fiber [5].

The development trend of aramid fiber involves upgrading the application products through advanced technology, developing differentiated products, achieving the application requirements. Presently, domestic para-aramid fiber is mainly applied in the fields of high-temperature filtration, protective materials, and sealing materials. However, in the application fields of tires, rubber products, and electronic communication equipment, particularly in high-end fields such as aviation, aerospace, national defense, and the military industry, which require high mechanical performance, domestic para-aramid fiber exhibits poor competitive performance compared to foreign products.

The development trend of UHMWPE fiber involves the development of differentiated products for high-end fields. The company DSM has led the high-end application of UHMWPE fiber and has developed fiber products with a strength greater than 40 cN/dtex. Creep-resistant fiber has been used in high-strength and creep-resistant rope. Recently, DSM successfully developed ultra-low creep fiber with a creep elongation of 0.5% under standard measurement conditions, which has been adopted successfully in the mooring lines of an offshore oil production platform.

The development trend of PI fiber is in the reduction of production cost. The main methods for this include exploring new monomers and their polymerization methods and developing polymer modifications and highly efficient spinning technology. PI fiber and flame-retardant viscose blend textiles result in intrinsic flame-retardant characteristics.

The development trend of PPS fiber is improving the fiber quality and developing differentiated products. Presently, domestic PPS fiber products are relatively single, mainly conventional staple fiber products. A significant gap exists between domestic PPS fiber products and Toray products in terms of fineness, crimp rate, and dry heat shrinkage properties. Domestic products of PPS fiber, such as fine denier (<1.0 dtex), profiled cross-section, and high crimp fibers, have not yet been industrialized.

4.3 Bio-based fiber

Lyocell fiber is a typical green fiber product, which exhibits outstanding performance advantages compared to viscose fiber. The future development focus on the Lyocell fiber is on achieving high quality, low cost, and wide application via technical improvements. Moreover, functional Lyocell fiber will undergo rapid development and exhibit high added value, such as flame-retardant fiber, anti-pilling fiber, and other varieties [6].

The poor heat resistance of PLA fiber poses difficulties in the subsequent textile, dyeing, and finishing processes, as well as clothing ironing. Therefore, improving the heat resistance of PLA fiber will be a development trend in the future. It is necessary to develop the preparation technology of D-type PLA and the stereoisomeric compound.

Recently, PTT has primarily been applied in the fields of engineering plastics and film, in addition to the preparation of fibers internationally.

Pentanediamine, which is the primary raw material of bio-based PA56 fiber, has undergone a breakthrough in industrialization. Furthermore, significant progress has been made in the industrialization of glutamine, which is the key raw material of bio-based PA56 fiber, and leading industrialization technologies and equipment for the preparation of glutamine by biological methods and bio-based polyamide have been developed. The first pilot-scale production line of bio-based polyamide industrialization has been established and operated successfully. The key point for polymerizing PA56 is the development of continuous and large-scale production, the achievement of melt direct spinning, and the simultaneous expansion of new application fields.

5 Key tasks for the development of advanced fiber material industry in China

In general, the goals for the advanced fiber material industry in China are as follows: the establishment of a reasonable layout and dynamic industrial technology innovation system; formation of a batch of original innovation achievements with independent intellectual property rights; establishment of a high-efficiency transformation mechanism of scientific and technological achievements; implementation of numerous laboratories and talent teams with international influence; formation of the innovation capability of the fiber material industry; and cultivation of backbone enterprises with international competitiveness. These efforts will facilitate a fundamental solution to the structural overcapacity, an increased proportion of medium- and high-end products in China, the green and intelligent levels of fiber materials reaching the international leading position, and the entire textile industry being driven into the middle- and high-end value chain.

5.1 Development of key technologies to form key characteristic products

5.1.1 Super-simulation fiber

For super cotton- and super wool-like fibers, the key task is to achieve breakthroughs in the design of the following: novel molecular structures and controllable polymerization technologies; high-proportion, accurate addition, and stable dispersion technology for functional powder; activity control and application technology of non-heavy metal catalytic systems; precise control technology for the cross-sections of high-profiled fine denier fiber; one-step processing technology for highly homogeneous fiber with multiple components and other key technologies. The aim is to improve the hygiene properties of super-simulation fiber and develop super-simulation fiber with high quality.

5.1.2 Flame-retardant fiber

With a focus on polyester fiber, PA fiber, and regenerated cellulose fiber, vital work is required in the following design areas: molecular structures and green manufacturing technology for environmentally friendly flame-retardant fiber; stretchable and efficient preparation technology for long-term flame-retardant fiber; design, processing, and finishing technology for flame-retardant fiber textiles; and the development of ecological long-term flame-retardant fiber with a high extreme oxygen limit index, low smoke emission, and droplet resistance, which facilitates the realization of the large-scale market application of high-quality flame-retardant fiber.

5.1.3 Electrically conductive fiber

Regarding polyester fiber, PA fiber, and PAN fiber, emphasis should be placed on the following: the processing technology of conductive functional powder with ultra-fine and narrow distributions; surface modification technology for functional powder; preparation technology for easy flowing and anti-agglomeration conductive masterbatches; high-efficiency spinning technology for high solid content spinning melt composite molding; preparation technology for high-metal ion-loaded conductive fibers; and the exploration of conductive fibers with low resistance to satisfy the requirements of intelligent wearable applications.

5.1.4 High-performance industrial yarn

Crucial studies on polyester fiber and PA fiber should focus on the following: modification technology for high-viscosity melt; preparation technology for high-uniformity melt; spinning technology for high molecular weight resin and its special additives; conveying technology for high-viscosity melt; controllable technology for viscosity drop and spinning uniformity; high-flow spinning technology of high-viscosity melt; high-multiple multi-stage drawing and setting technology for industrial yarn; and surface activation technology for low-energy irradiation. Quality control, testing standards, and evaluation methods need to be established for high-performance industrial yarn. Moreover, high-performance industrial yarn with high strength, high modulus, and low dry heat shrinkage needs to be developed.

5.1.5 Geotechnical construction reinforced fiber

For PAN fiber, polyvinyl alcohol fiber, and polypropylene geotechnical materials, key studies will focus on the following: large-scale preparation technology for high-strength and high-modulus polyvinyl alcohol fiber; large-scale preparation technology for high-strength, high-modulus, and easy-dispersion polyacrylonitrile fiber; preparation technology for high-strength and anti-aging coarse denier polypropylene spun-bonded needle geotextiles; and high-efficiency construction technology of textiles for the reinforcement of geotechnical construction. Engineering fiber textile services and failure warning mechanisms should be established to realize the application of 10 000 t of reinforced materials for geotechnical engineering.

5.1.6 High-performance fiber

Key research on carbon fiber should focus on the pilot-scale test technology of M60J, and the realization of the continuous and stable production of 100 t of M55J. For para-aramid fiber, the main focus should be on improving the quality of products, developing differentiated products, constructing intelligent production lines with a 10 000 t capacity, increasing the global market share, and accounting for more than 80% of the domestic market. For the UHMWPE fiber, key research should be the focused on the development of environmentally friendly and efficient solvents and innovative production routes, the exploration of efficient and safe new equipment, and realization of scale production of higher-performance UHMWPE fiber. For PI fiber, the efforts should mainly focus on the development of high-strength and high-modulus fiber with a strength and

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modulus of 4.2 GPa and GPa, respectively, and the exploration of extensive applications in structural composites. For PPS fiber, the vital work should be research on fiber-grade PPS resin with a high quality and low cost, the realization of continuous spinning of PPS fiber and its applications in industrialization, improvements in PPS fiber with heat and oxidation resistance, and the expansion of their application markets.

5.1.7 Bio-based fiber

For Lyocell fiber, it is necessary to develop technology and equipment with a single-line production capacity that is greater than 6×10^4 t/a, as well as the generation of novel low-cost antigen fibrillation technology and equipment with a production capacity of more than 3×10^6 t/a. For PLA fiber, the key work should be the high-efficiency preparation, purification, and industrialization technology of lactide and a production capacity of PLA that reaches approximately 3×10^5 t/a. For PTT fiber, the focus should be on the efficient preparation, purification, and industrialization technology for bio-based PTA, and the production capacity of bio-based PTT should reach approximately 2×10^5 t/a.

5.2 Improvement of intelligent manufacturing technology

The technical level of intelligent manufacturing should be promoted constantly in chemical fiber materials to achieve a comprehensive breakthrough in the new generation of foundation and support technology for fiber. New technology for intelligent fiber manufacturing and smart fiber material technology should be preliminarily completed. Initially, the generation of novel intelligent fiber manufacturing platform systems that are driven and enabled by artificial intelligence should be improved; a state crucial laboratory and a science and technology innovation center for the intelligent manufacturing of the fiber industry in China should be constructed, and an international talent highland for intelligent fiber manufacturing technology should be formed. It is estimated that the overall level of intelligent manufacturing technology in the Chinese fiber industry will reach the international advanced level by 2025.

The R&D and engineering applications of intelligent manufacturing technology in the textile industry should be strengthened. Based on the intelligent manufacturing standards, common technologies, and assembly technologies of the textile industry, and with a focus on the layout of the textile industry chain, novel intelligent textile manufacturing model technologies should be developed, such as intelligent workshop (factory) technology, large-scale personalized customization technology, networked textile manufacturing, and the remote operation and maintenance of textile equipment. Considering the development of the intelligent textile industry, it is necessary to establish intelligent textile material technology to construct intelligent manufacturing technology systems for the textile industry.

An intelligent manufacturing platform system and state key laboratories for intelligent manufacturing should be established for the textile industry, covering the basic and supporting technologies of intelligent manufacturing, the novel technology for intelligent manufacturing, and the technology for intelligent textile materials. State engineering technology research centers with intelligent manufacturing standards and generic technologies for the textile industry should be developed. Internet of Things and big data platforms should be developed for the textile industry, and several intelligent textile manufacturing cloud platforms for enterprises in the textile industry cluster area should be created.

5.3 Strengthening of independent innovation capacity

Presently, the Chinese fiber material industry is not strong, and its science and technology innovation systems are incomplete. The significant challenges facing the industrial development have not been effectively addressed for a long time, including the weak independent R&D capability of enterprises, an insufficient supply of key common industrial technologies, a severe lack of technical innovation services for small- and medium-sized enterprises, a lack of systematic planning for industrial innovation and development, and the disordered allocation of innovation resources. In this regard, the following areas need to be strengthened:

(1) The innovation development strategy of the national fiber industry technology should be improved. To conduct in-depth studies on the industrial technology innovation strategy, develop technical routes and development plans, and present policy suggestions to guide industrial development, it is suggested that a strategy committee for the innovation of the national fiber industry technology be established, which will be composed of relevant government departments, key enterprises, and scientific research institutes.

(2) To promote the technical innovation ability in disruptive and pre-competition technologies, a national fiber material innovation center needs to be established, and national key laboratories and engineering technology research centers should be constructed.

(3) The technology innovation strategic alliance of the chemical fiber industry and the newly generated textile equipment industry established in the fiber industry have become novel organizations that lead and support technological innovation in

the fiber industry. To optimize the operation mechanisms and improve the industrial technology innovation chains, the guiding role of government resources should be provided full support to encourage and support these alliances. Moreover, the formation of numerous industrial technology innovation strategic alliances in emerging areas should be accelerated, such as high-performance fibers and composites, bio-based fiber materials, and the construction of technological innovation chains around the industrial chain.

(4) Service platforms of technological innovation in industrial agglomeration areas should be developed and improved. With the investment of local governments and enterprises as the main input, specialized technology innovation service platforms should be constructed and improved in Yangtze River Delta, Pearl River Delta, Fujian, and other industrial agglomeration areas or industrial parks. To provide high-efficiency and low-cost professional services for small- and medium-sized enterprises via preferential policies and purchase services, the government should support these platforms.

(5) Backbone enterprises need to be supported to enhance their technological innovation ability. In the field of the key varieties and equipment of fiber, the backbone enterprises should be supported to increase investment in science and technology, strengthen the construction of R&D institutions and R&D systems, increase "industry–university–institute" cooperation, and enhance the independent innovation ability of enterprises. Qualified backbone enterprises should be encouraged to absorb innovative resources globally and to enhance their international competitiveness.

(6) The evaluation and standard system of material application technology should be improved. Fiber material standard laboratories should be established, with a focus on the development of material testing standards and product standards. Product application technology evaluation centers should be established, and support should be provided for market application promotion and technology transfer by standardizing products and evaluation methods, and the industrial application of fiber materials should be promoted. The basic support and promotion of the material standard system should be highlighted in product innovation to improve the international level of standards and to enhance the international discourse power.

5.4 Enhancing training of scientific and technological talents

The following goals should be met: enhancing the construction of leading talents in the field of fiber industry engineering science and technology, and related basic research fields; strengthening the construction of national innovation teams in various fields and directions of science and technology in the fiber industry; establishing a standards system; promoting the training of technical personnel and technical workers in fiber enterprises; improving the overall quality of enterprise personnel; changing the structure of knowledge and ability; developing the intelligence of higher education in the textile industry, introducing higher vocational and technical education and secondary vocational and technical education in the direction of manufacturing technology; and cultivating multilevel and complex intelligent textile manufacturing professionals. Moreover, high-end personnel in novel fiber materials, as well as basic fiber science and technology research, should be introduced globally.

6 Countermeasures and suggestions

According to the domestic demand and international competition regarding the development of the Chinese fiber industry, the following countermeasures and suggestions are proposed owing to the extrusive limitations in the development of advanced fiber materials.

6.1 Strengthening of research on industrial development strategy

Experts in scientific research, production, design research, industry management, finance, and investment should be gathered to establish a reasonably structured and stable research team for a high-level industrial development strategy. Given the important practical issues in the development of the advanced chemical fiber materials industry, such as scientific and technological innovation, the combination of industry and finance, modern industrial chains and industrial clusters, industrial transfer and international competition, continuous and in-depth systematic research should be conducted, and the development status and planning implementation should be tracked and evaluated. Moreover, to provide reliable guidance for the policy-making of China in a macrocosmic sense, particularly regarding the decision making in production enterprises, financial investment institutions, and scientific research institutions, the outline of the plan should be timely adjusted and continuously improved.

6.2 Improvement of construction of industrial innovation system

Following the general requirements of deploying an innovation chain around the industrial chain and arranging the industrial chain around the innovation chain, the layout of key laboratories of the state and ministries should be improved. Furthermore, full leverage should be given to the coordination mechanism between laboratories and the research on major scientific issues of fiber and maintenance materials and engineering. Support from the government should be increased, a team engaged in high-level basic research should be established, and a batch of original innovation achievements should be produced. The role of government guidance and policy guarantees should be enhanced, venture funds and industrial funds should be attracted, the pilot research and engineering research capabilities of engineering research centers should be improved, the transformation mechanism of innovation achievements should be optimized, and the formation of numerous major industrialization technology achievements should be accelerated. Furthermore, the strategic alliance of industrial technology innovation should be supported and encouraged to play an important role in the collaborative innovation of the industrial chain, and to accelerate the market application of scientific and technological achievements. Intermediary service agencies need to be supported and encouraged to improve their services and credibility continuously, as well as to play a role in the standard development, intellectual property services, evaluation and transformation of scientific and technological achievements, and brand building.

6.3 Enhancement of leading role of science and technology

Regarding the advanced industrial base and modernization of the industrial chain, innovation chains should be comprehensively deployed, with a focus on the fields of manufacturing technology and equipment for polymer and fiber. To ensure that the key varieties have independent intellectual property rights and the ability for continuous technological iteration and improvements, the scientific and technological resources of key laboratories, technological centers, and key enterprises should be integrated and industry–university–institute cooperation should be established. The industrial chain should be established based on the innovation chain, the chemical fiber industry foundation and venture capital should be promoted, financial support for the development and application of original innovative fiber varieties should be increased, the commanding point of science and technology should be occupied, and advantageous industries should be established. The transformation and development of engineering companies need to promote solution service providers and innovative business models. Scientific and technological resources should be integrated, and comprehensive service models for the industry chain and supply chain management should be constructed. High-level science and technology service enterprises should be established to improve the comprehensive capabilities of technology R&D, as well as the engineering transformation of engineering companies.

6.4 Support of internationalization of key enterprises

Large enterprises in developed countries could occupy a dominant position in international competition by gathering industry–university–institute innovation resources, expanding the capacity scale of key varieties, and extending the industry chain. Presently, several domestic enterprises already possess substantial production capacity, operation and management, and industry–university–institute cooperation. Substantial support should be provided to these enterprises with the objective of extending the industrial chain, enabling the global distribution of the production capacity and innovative resources, and increasing the industry–university–institute cooperation. The investment of social capital, such as industrial funds, should be guided, and the formation of multinational enterprises with international competitive advantages should be accelerated to lead the development of the advanced fiber materials industry of China.

6.5 Coordinated development of materials, high-end equipment, and intelligent manufacturing

Based on the development trend of the integration of advanced fiber materials and intelligent manufacturing technology, the integration and development of advanced fiber materials and high-end equipment need to be promoted. The key technologies and equipment need to be leveraged, the application of domestic equipment and intelligent manufacturing systems should be promoted, and the overall improvement of the industry manufacturing level should be advanced. The original R&D capabilities of intelligent, differentiated, and functional equipment, as well as high-tech fiber equipment, should be strengthened, the R&D and industrialization capabilities of major technologies and complete sets of equipment should be enhanced, the added values of products should be improved, and thorough transformation and upgrading of the chemical fiber industry should be facilitated by the progress in equipment technology. Breakthroughs in the digital and intelligent key technologies of the chemical fiber manufacturing process should be accelerated, the application of domestic equipment and intelligent manufacturing systems in the industry backbone enterprises should be expanded, the safety of the data and industry of China should be ensured, and the international competitiveness of the chemical fiber industry should be enhanced.

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