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Development and Prospect of High-Performance Polymer Composites in China

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Abstract: High-performance polymer composites have become indispensable strategic materials in national defense and economic development projects owing to their excellent comprehensive properties. Further, they have broad development prospects, as evidenced by their diverse applications, including in the aerospace sector, wind-power generation, rail transit, and automobiles. In this study, China's macro development requirements for high-performance polymer composites are analyzed. The current state and characteristics of fiber reinforcements, including carbon fiber, aramid fiber, and high-performance glass fiber, as well as polymer resin matrix materials such as epoxy, phenolic resin, and special resin, are reviewed. Furthermore, the existing problems and development objectives are discussed. Specifically, an industrialization system considering key technology research and engineering applications for carbon fiber has been established, facilitating the advancement of the carbon fiber industry toward high-performance and low-cost composite materials. The industrial production of para-aramid fiber has been preliminarily realized, and the glass fiber industry has maintained stable growth. However, the application of resin matrix materials to achieve high-performance polymer composites has several limitations. Furthermore, based on the development requirements, recommendations centered on independent innovation, demand orientation, construction of industrial chains, personnel training, and industrial innovation are proposed to provide an effective reference for the development of the high-performance polymer composite industry in China.
Keywords: high-performance fiber; polymer resin matrix; composites

1 Introduction

High-performance polymer composites are a class of materials represented by fiber-reinforced epoxy resins (reinforced by carbon fiber, aramid fiber, glass fiber, etc.) and high-performance resins (e.g., bismaleimide resin). Owing to their excellent comprehensive performance, they have become indispensable strategic materials in national defense and economic development projects. As the key basic materials in advanced equipment, high-performance polymer composites are essential for achieving lightweight structures and ablative heat-protection components for aerospace and aviation weapons, including the new generation of weapons and major technologies (e.g., hypersonic vehicles, near-space vehicles, and deep space exploration vehicles). Additionally, high-performance polymer composites are widely applied in various important sectors that contribute to the national economy, such as advanced industrial manufacturing, rail transportation, and clean energy.

Presently, the global high-performance polymer composite industry is relatively mature and is developing steadily. Among reinforcement materials, carbon fiber has attracted significant interest; the research on this material is geared toward achieving specialized high-performance and large-scale industrial low-cost production, since it is the most

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important reinforcement of advanced composite materials. Regarding para-aramid, increasing efforts have been devoted to the construction of its industrial chain. The trend of technique integration is becoming increasingly common, and new application fields are emerging. The glass fiber industry has formed a complete industrial chain from fibers and products to composite materials. Regarding plastic resin, stable development has been maintained in recent years, and automated manufacturing techniques are becoming increasingly popular. Notably, aerospace composite technology has reached a mature stage, and wind-power generation and automotive applications have injected vitality into the carbon–fiber composite industry. Thermoplastic composites have broad application prospects in the rail transport and automotive industries.

Recently, with the increase in the demand for high-performance polymer composites in aviation, aerospace, wind-power generation, rail transportation, automobile, high-pressure containers, and other sectors, a preliminary high-performance polymer composite industry was successfully established in China. The application range and production capacity are expanding continuously, and the production processes are gradually shifting toward achieving low-cost and high-performance materials. However, compared with advanced countries, there is still significant room for improvement in the high-performance polymer composite industry in China. Therefore, based on the current situation and characteristics of various fiber reinforcements and resin matrices in the high-performance polymer composite industry in China, the manufacture and application of composite materials are reviewed in this paper. Additionally, the current challenges and the reasons for the deviation from the international standards are discussed. Finally, development directions and suggestions for advancing the high-performance polymer composite industry in China are proposed.

2 Demand for high-performance polymer composite materials in China

High-performance polymer composites are not only indispensable strategic materials for national defense and economic development, but also the foundational materials in many key areas indicated in *China Manufacturing 2025*. With the transition of the national strategy in China and the proposal of novel ideas for economic development, the development and application of high-performance polymer composites have become imperative.

2.1 High-performance polymer composites, as basic materials in national security projects

With the implementation of the innovation-driven development strategy in China, the aerospace, aviation, and marine industries have become the foundation for promoting the national power. Advanced, multifunctional, composite materials with high performance and structure–function integration are essential for the research and development of strategic missiles, new armor, naval vessels, large aircraft, new-generation fighter planes, and satellites. Unfortunately, composite materials and structural components have become bottlenecks hindering the completion of major national safety engineering projects. For example, there is a high demand for high-strength and medium-modulus carbon fiber composites in the development of missiles, aero engines, and hypersonic aircraft. The implementation of domestic large aircraft, advanced satellites, and lunar exploration engineering projects requires high-strength, high-modulus carbon fibers and their composites.

2.2 High-performance polymer composites, as key materials for technological innovation

In advanced manufacturing sectors/machines, including aviation and aerospace, marine engineering equipment and high-tech ships, advanced rail transportation, energy-saving and new energy vehicles, new material industry, electric power generation equipment, new information technology industry, advanced machines and robots, and high-performance medical, high-performance polymer composites are essential for realizing technological revolution. For example, by employing carbon fiber composites in the beam cap and main beam of a wind turbine blade with a length of more than 40 m, the blade weight can be reduced by approximately 38%, and the cost can be reduced by approximately 14%. Furthermore, the fatigue resistance of the blade is improved and the output power is increased. Therefore, it is relatively easy to produce adaptive wind turbine blades with large diameters using carbon fiber materials.

2.3 Importance of high-performance polymer composites in green development

For limited energy innovation, saving energy and reducing emissions are important research goals in the automotive industry, and introducing lightweight materials is one of the keys strategies for realizing these goals. Advanced polymer composites have many outstanding advantages, such as high specific moduli and strengths, high

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weight reduction potentials, and high safety degrees. With the continuous advancement in composite technology, carbon fiber composites have been employed in automobile bodies, tails, chassis, hoods, and interiors. In the near future, the demand for carbon fiber in the automotive industry will increase to approximately 7%.

3 Development of high-performance polymer composites in China

Although substantial progress has been made in the development of high-performance polymer composites in China, the industrial process for the fabrication of high-performance fiber reinforcements, resin matrices, and composite materials is relatively slow. There is still a huge gap compared to the processes in advanced countries.

3.1 Different development characteristics for several kinds of high-performance fibers

3.1.1 Formation of the R&D and production system for carbon fiber and its rapid advancement toward high-performance and low-cost materials.

Carbon fibers are a class of inorganic fibrous materials with a carbon content of more than 90%, among which polyacrylonitrile (PAN)-based carbon fibers are the most important. The fabrication process of PAN-based carbon fibers mainly includes the following steps: the preparation of the acrylonitrile (AN) polymer solution, spinning of the PAN precursor, preoxidation, and carbonization, followed by high-temperature graphitization to afford high-modulus carbon fibers. Surface treatment is also required to reinforce the polymer matrix [1]. The fabrication process of PAN-based carbon fibers is shown in Fig. 1.

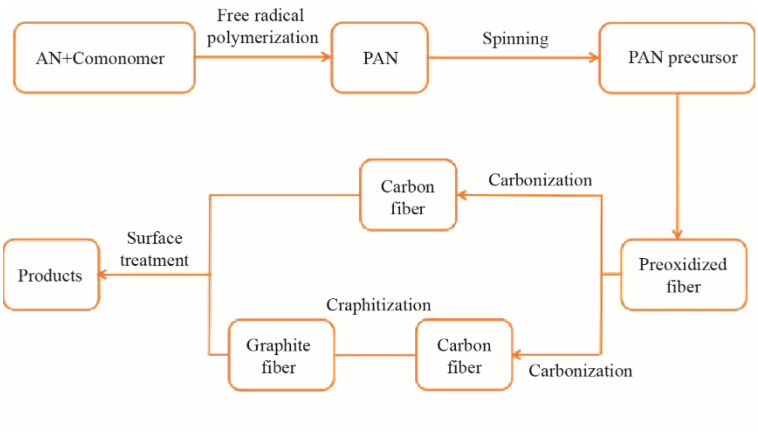

Fig. 1. Fabrication process of PAN-based carbon fibers.

With the support of the national government, major advancements in high-performance carbon fiber production and application in China have been achieved through collaborative development over the past 10 years [2].

(1) A series of high-performance carbon fiber technologies and products was established with continuous improvement.

Presently, T300- and T700-grade domestic carbon fibers are already manufactured industrially. The performance of the T300-grade domestic carbon fiber has reached international standards, and its application in the defense industry is becoming increasingly pronounced. However, the application of domestic carbon fiber in the civil field still needs to be developed. T700- and T800-grade high-performance carbon fibers can be obtained through wet and dry-wet spinning techniques, and their industrial production has been achieved. The wet spinning method for fabricating T700-grade carbon fiber has been developed innovatively, and its related products have been applied in the aviation sector. The preparation of T1100-grade high-performance carbon fiber has been achieved in the laboratory. As high-modulus and high-strength carbon fibers, M40-grade high-modulus carbon fibers have been produced, with a production capacity of approximately 300 kg/a; these fibers have been developed and applied in satellite models. M55J-grade high-strength and high-modulus carbon fibers are still in the engineering development stage, and various higher-performance carbon fibers are still under development in the laboratory.

(2) Numerous carbon fiber manufacturing enterprises and R&D platforms have been established, and the distribution of the domestic carbon fiber enterprises is increasing.

In China, there are more than 20 enterprises producing carbon fibers, which are mainly distributed in Shandong, Jiangsu, Hebei, and Jilin provinces. Basically, the domestic carbon fiber enterprises are well distributed. Six enterprises, including Weihai Tuozhan Fiber Co., Ltd., Jiangsu Hengshen Co., Ltd., Zhongfu Shenying Carbon Fiber Co., Ltd., Zhonganxin Technology Co., Ltd., Jilin Jinggong Carbon Fiber Co., Ltd., and Sinopec Shanghai Petrochemical Co., Ltd., have built more than 10 production lines with a capacity of 1000 t. Another 18 enterprises have built production lines with a single line having a production capacity of several tens or hundreds of tons. Jilin Carbon Valley Carbon Fiber Co., Ltd. built a production line with a capacity of 1.5×10^4 t/a for the PAN precursor. In 2019, the theoretical production capacity of domestic carbon fiber reached 2.6×10^4 t/a, and the effective production capacity was approximately 1.5×10^4 t/a. Consequently, the demand for the T300/T700 grade carbon fiber for national defense applications was met. However, some problems still exist, including the low yield and insufficient production time.

For the R&D platform construction, many carbon fiber science and technology research institutions have been built in China to support the local development of the carbon fiber industry, including one national carbon fiber engineering technology research center, two national engineering laboratories for carbon fiber preparation technology, two national engineering laboratories for carbon fiber composites, and several national key laboratories.

3.1.2 Although the industrialization of para-aramid fibers is successful, there is still a large gap compared with the advanced international standard.

Para-aramid is an important member of the para-aromatic polyamide fiber family. The p-phthaloyl-p-phenylenediamine polymer is prepared by the polycondensation of p-phthaloyl chloride and p-phenylenediamine; thereafter, the aramid fiber is prepared by solution spinning. The total production capacity of para-aramid fibers globally is approximately 7.6×10^4 t/a, and the operating rate is approximately 70%–80%. Presently, eight enterprises in China have built production units for para-aramid fibers, and the total production capacity has exceeded 7×10^3 t/a. The specific production capacity distribution is shown in Fig. 2. However, the actual annual yield in China is approximately 1.8×10^3 t, and the operating rate is less than 30%. Generally, there is a large gap between Chinese para-aramid industrialization levels and advanced foreign levels, and strong competitiveness is yet to exist in terms of industrial scalability, product quality, and application [3].

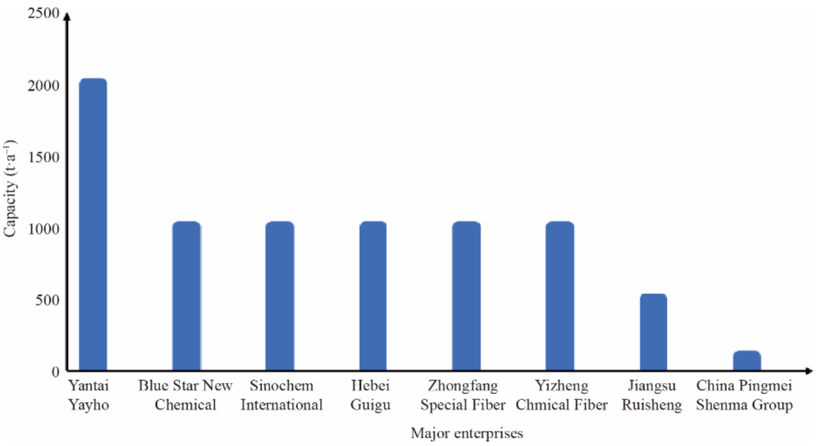

Fig. 2. Production capacity of the main domestic enterprises for para-aramid in 2017.

For the R&D platform construction, many national and local research and technology platforms for aramid fiber have been established in China. For example, Donghua University is the supporting institution for the State Key Laboratory of Fiber Material Modification. The South China University of Technology is the supporting institution for the State Key Laboratory of Pulp and Paper Engineering. Yantai Taihe New Material Co., Ltd. is the supporting facility for the national aramid fiber engineering center, and the China Bluestar Chenguang Co., Ltd Research Institute of Chemical Industry Co., Ltd. is the R&D platform for multivariety and small-batch military materials using fiber and other polymer materials.

3.1.3 China is the global leader in terms of the production capacity of glass fiber, maintaining appropriate growth.

Glass fiber is an excellent functional and structural material. The glass fiber production capacity of China in 2016 was approximately 3.8×10^6 t/a, accounting for 60% of the total global capacity. From 2017 to 2019, the annual complex growth rate of China's glass fiber production capacity was 6.65%, which is considerably higher than the

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global rate of 1.70%. The annual yield of glass fiber in China increased from 9.5 × 10^5 t to 3.62 × 10^6 t in 2015–2016, with an average annual growth rate of 12%. Over the 13th Five-Year Plan period, the production capacity of glass fiber has been growing steadily. The new capacity is mainly enabled by a few enterprises; for example, China Jushi Co., Ltd. has completed the improvement of five production lines, Taishan Glass Fiber Co., Ltd. has built a new tank furnace production line, and Chongqing International Composite Materials Co., Ltd. has built a cold repair line.

3.2 Challenges of producing high-performance epoxy resin and phenolic resin

3.2.1 Epoxy resin

Epoxy resin is a thermosetting resin that is produced by the condensation polymerization of epichlorohydrin and bisphenol A. It is widely used as a matrix resin in composites, particularly in the aviation sector. In 2016, the total global production capacity of epoxy resin was approximately 4.62 × 10^6 t/a. Presently, the Dow Chemical Company, Nan Ya Plastics Corporation, and Momentive Performance Materials are the top three companies globally, accounting for 37% of the total production capacity. In 2017, the production capacity of the Chinese epoxy resin industry was 2.3 × 10^6 t/a, accounting for 50% of the total global capacity, with a yield of 1.2 × 10^6 t. In China, 9% of the epoxy resin produced is used in the field of composite materials, and the rest are employed in the fields of electronics, coatings, adhesives, etc.

O-cresol epoxy resin is an epoxy resin obtained by replacing bisphenol A with an o-cresol epoxy resin. It has a higher epoxy value than bisphenol and can provide a 2.5 times higher crosslinking point during curing, endowing the composite with high thermal stability, mechanical strength, electrical insulation, and chemical resistance. Presently, the global market for o-cresol epoxy resin is monopolized by companies in Japan, and the United States, Switzerland. High-purity and high-quality o-cresol epoxy resins cannot be produced on a large scale in China.

Generally, epoxy resin is cured to form a crosslinked network stereopolymer, which envelops the composite bone in the network. According to the temperature, the curing process can be divided into room temperature curing (20–30 ℃), medium-temperature curing (50–130 ℃), and high-temperature curing (>130 ℃). Compared with high-temperature curing, medium-temperature curing has many advantages, such as low temperature, fewer requirements for mold, low internal stress, and stable size. To avoid the problems of low toughness and brittleness of the cured epoxy resin, toughening is required, which is achieved via rubber elastomer toughening, high-performance thermoplastic polymer toughening, and thermotropic liquid crystal polymer toughening. In addition, flame retardant modification of the epoxy resin is required, and halogen-free flame retardants have been widely studied and applied in recent years. The functional monomer with a certain amount of nitrogen, silicon, or phosphorus in the molecular structure can be used as a reactive monomer or curing agent for the flame-retardant epoxy resin, which improves the flame retardancy of the resin composite. Presently, domestic flame-retardant manufacturers, including Zhejiang Wansheng Co., Ltd. and Jiangsu Yoke Technology Co., Ltd., have begun to produce organophosphorus halogen-free flame retardants; however, the overall process level is still considerably below those in developed countries.

3.2.2 Phenolic resin

Phenolic resin, a matrix resin widely used in composite materials, is a thermosetting resin formed by the condensation of phenolic compounds (such as phenol) and aldehydes (such as formaldehyde). One of the most typical and important phenolic resins is that formed by the condensation of phenol and formaldehyde. In 2016, there were more than 200 phenolic resin manufacturers in China, with a total production capacity of 1.3 × 10^6 t/a and a yield of 1.02 × 10^6 t, ranking first in the world. However, these manufacturers have not yet mastered the techniques for fabricating some high-performance phenolic resins and their composites, as well as casting technologies. Therefore, there is an urgent need to improve the level of the domestic enterprises that engage in phenolic resin modification and casting.

Phenolic resins with high brittleness and low elongation possess easily oxidizable phenolic hydroxyl and methylene groups. To meet the performance requirements of phenolic resins in aviation, aerospace, and other advanced sectors, toughening and heat-resistant modifications are required. Among the existing modified phenolic resins, boron-modified phenolic resins, formed by the introduction of boron into the molecular structure of the phenolic resin, are excellent variants with high performance. They have the characteristics of a high oxygen index, low toxicity, and low smoke, and they are some of the most important materials urgently required in the research and development of rockets, aerospace, missiles, nuclear power stations, and automobile brake pads [4].

3.2.3 Special resin matrix

Special resin matrices, including bismaleimide resin, cyanate ester resin, and benzoxazine resin, exhibit good heat resistance, flame retardancy, radiation resistance, wave transmission, electrical insulation, and mechanical properties. They are considered thermosetting polymer matrix resins with broad development prospects. They are expected to be the successors of epoxy resins and are widely used in the fields of aviation and aerospace. In the fourth-generation fighter F-22 jet of the United States, composite materials account for 24% of the total structural weight, of which 70% is composed of bismaleimide resin matrix composites [2]. Over the last 30 years, the United States, Japan, Britain, Germany, and other countries have carried out many modification studies on the bismaleimide resin and other special resin matrices to prepare outstanding matrix resin materials. Compared with the advanced international standard, there is a large gap in the scale of mass production and product stability in China.

As high-performance materials, special resin matrix composites have two major functions in practical applications: (1) improve the processability of the resin by copolymerization, blending, or other methods, and solve the problems of brittleness and fracturing caused by the solid-phase high-temperature curing; (2) improve the toughness while ensuring that the material has a high heat resistance and mechanical properties. Therefore, composite materials with excellent properties, such as strength, toughness, heat resistance, and processability, have been prepared to meet the requirements of the aviation, aerospace, and other military industries.

3.3 Manufacture and application of composite materials in China have advanced significantly

3.3.1 The composite technology has reached the mature stage and is applied on a large scale.

(1) In the aviation sector, the application technique of composite materials has been improved, and the proportion of composite materials used is increasing. For example, composite materials are employed in 25% of China's fourth-generation fighter jets and 15% of large transport aircraft; further, the proportion of composites in a certain type of helicopter is 34%. In addition, there is an ongoing plan to employ carbon fiber composite materials in the tail, wing, and other parts of a large airliner, and the composite materials will account for 15%–25% of its structural weight. (2) In the field of aerospace, with the continuous improvement in the resin matrix properties and the gradual application of advanced technology, the application potential of composite materials in aerospace structures in China is increasing from small secondary bearing structures to large primary bearing structures. (3) Glass fiber- and carbon fiber-reinforced composite materials are mainly used in ammunition and rocket weapons in the ordnance industry, and their application range has been expanded from non-load-bearing and secondary load-bearing structural parts to main load-bearing structural parts, such as high internal pressure rocket engine shells with high overload resistance and large-diameter armor-piercing sabots. According to an incomplete statistics report, the annual consumption of glass fiber has reached more than 1000 t, and the annual consumptions of carbon fiber, aramid fiber, and polyethylene fiber have reached more than 50 t, 70 t, and 10 t, respectively. (4) In the civil field, the applications of wind-power generation and automobiles have provided new vitality to the carbon fiber composite industry, and the application prospects of thermoplastic composites in rail transportation and automobile industries are broad.

3.3.2 The automatic manufacturing technique of composite materials is advancing considerably.

With the diverse applications of high-performance composite materials, the manufacturing process of composite materials is shifting rapidly toward diversification and automation. The molding process of composite materials has advanced from 2–3 types (hand lay-up and manual lay-up) to nearly 10 types (automatic lay-up). Automatically manufactured composite components accounted for 50% of the total composite components in 2016 and reached more than 65% at the end of 2020.

Over the 12th Five-Year Plan period, the automatic manufacturing technology of composite materials in China has been well developed, and advanced and efficient technologies, such as automatic tape laying, automatic wire laying, and automatic pultrusion of prepreg, have been gradually applied. Hot melt prepreg production and autoclave composite material forming technology, fiber/cloth tape-winding forming technology, and resin transfer molding (RTM) forming technologies have been developed for the development and small-scale production of carbon fiber, glass fiber, aramid-reinforced high-performance phenolic resin, epoxy resin, bismaleimide resin, polyimide, and other composite materials. These materials are mainly used in automobiles, rail transportation, communication power generation, building materials, electric power or electrical appliances, municipal infrastructure, new energy development, and other fields, and their production meets the needs of the aviation, aerospace, weapon, energy, and transportation industries.

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3.3.3 Structural/functional composite material techniques are rapidly shifting toward high quality and practicability and supporting the development and production of advanced equipment.

In China, the technology of structural and functional integrated composite materials is advancing rapidly. Structural wave absorption and transmission composite materials have been widely used in new aircraft, missiles, ships, ground vehicles, etc. The high-strength glass fiber-reinforced resin matrix composite, which was the first-generation antibullet/structural composite material, has reached the American mil-46197a standard for structural armor composite materials, and it has been used in the hatch covers of a variety of armored equipment. The second-generation composite has the characteristics of multifunction integration, such as antiballistics, bearing, and stealth. While maintaining high stiffness and antiballistic performance, this material exhibits outstanding absorption properties in a wide radar wave band. It has been employed in the roof and the exposed parts of the large power cabin of tanks. Driven by the development plans for manned space flights and space exploration, honeycomb-reinforced low-density resin-based thermal composites have been developed and successfully applied in manned re-entry capsules.

High-performance carbon fiber composites are the core of the composite industry. In 2016, the global annual consumption of carbon fiber composites was approximately 1.1×10^5 t, and the total market capitalization was approximately 20 billion USD; thus, the market prospect is very broad. After more than 30 years of development of composite materials in China, numerous R&D platforms and manufacturing bases for composite components have been established to promote the improvement of composite technology and industrial standards.

4 Problems hindering the development of high-performance polymer composites

Presently, high-performance polymer composites represented by carbon fiber-reinforced composites are still in the initial development stages in China. There is still a large gap compared with the processes in advanced countries, particularly since the development is mostly based on imitations of existing foreign products. The high-level products are highly dependent on imports, and the industrialization process is relatively slow. Some important fields are developing at slower rates than those in advanced countries.

4.1 High-level carbon fiber products are few, and the cost of ordinary products is high; thus, the development of para-aramid is difficult.

The development of high-performance fibers in China is unbalanced. For high-performance inorganic fibers, glass fibers have reached the mature stage of industrial development with good product quality and high market share. Carbon fiber is in the initial stage of industrialization with continuous improvement in the production capacity, while the yield and market share are low, and the stability and quality need to be improved. Aramid fiber is in the early stage of industrialization, with a certain production capacity and stable product quality, while the yield and market share need to be further increased.

The cost of domestic carbon fiber remains high, and the high-performance carbon fiber used in the aviation, aerospace, and other sectors is inferior to those in foreign countries; therefore, independent innovation needs to be fostered. Moreover, the development of the application market for carbon fiber in China is slow. The requirements for various applications, such as wind-power generation and in automobiles, are few and not enough to prompt an increase in the carbon fiber production. The existing carbon fiber enterprises mostly produce T300-grade carbon fibers, and a disorderly expansion occurs at a relatively low level. In addition, foreign companies dump their medium- and low-grade carbon fiber products in the Chinese market to suppress domestic carbon fiber production. This is not conducive for the development of domestic carbon fiber enterprises, and it hinders the achievement of a competitive, sustainable, and healthy developing industry.

Regarding para-aramid, foreign companies continue to suppress China’s aramid products using low prices, thereby discouraging domestic enterprises from utilizing domestic products. Additionally, the aramid enterprises in China are faced with stringent regulations imposed by foreign countries on the import of the aramid monomer (p-benzoyl chloride), which hampers the development of the aramid industry.

4.2 R&D and the application level of the resin matrix are relatively low.

The resin matrix is the first damaged component in fiber-reinforced composites, which plays a key role in the overall performance of composites. The main limitations of the resin matrix in China are as follows: (1) R&D facilities are insufficient. The R&D facilities are mainly universities and institutes, which are relatively disjointed with the application research of composite materials carried out by enterprises; (2) the production capacities of high-quality and high-purity epoxy resin, phenolic resin, and modified high-quality products are still low; (3) to advance composite materials in high-level fields, the designed methods of the resin composite system need to be strengthened; (4) the industrialization potential of high-performance resin matrices is insufficient to satisfy the requirements of low frequency, omnidirectional stealth, wave transmission, low density, antiheat insulation, bulletproof, and other properties. In addition, it is necessary to strengthen the application of new supermaterials, frequency-selection methods, graphene, and other new technologies and structural materials with wave absorption and transmission.

4.3 Relatively low level of design, manufacture, and application of resin matrix composites

(1) The structural designs of composite materials in China are mainly imitations, and independent designs are minimal. Presently, according to the statistics of foreign applications, the weight-reduction efficiency of T300 carbon fiber composites can reach approximately 25%. Contrarily, in China, the weight-reduction efficiency is relatively low, i.e., less than 20%.

(2) The application of the domestic composite automatic forming process is not common, and the total composites formed by this process account for less than 20%. This process is mainly limited to advanced sectors such as aviation and aerospace. Traditional hand paste or manual laying molding is still the main mode of civil composite material molding, which is considerably below the level of automated manufacturing abroad. All these factors make the composite material performance unstable; further, the qualified rate of products is low, and the cost is high. This has become a prominent problem that restricts the development of high-performance composites.

(3) The key manufacturing technology is still not advanced. Important equipment for composite production are imported and imitated. Progress has been recorded in the development of some equipment, including hot melt prepreg, winding machines, hot pressing tanks, and hot press, as well as the composite automatic laying equipment and prepreg automatic extrusion equipment; however, the dependence on imported equipment for scientific research and production is still high.

(4) There is a gap between the application of high-performance resin matrix composites in China, compared to the case in advanced countries. The proportion of composite material in the ARJ 21 airliner, which was developed in China, is approximately 2%. The proportion of composite material in the C919 medium-sized passenger aircraft under development is approximately 10%, while those in Boeing 787 and Airbus A350 are more than 50%. The proportion of composites in the NH90 helicopter from a European helicopter company was as high as 95%, while that in the domestic new helicopter (Z10) was only 34%. The large-scale application of high-performance resin-based composites in large aircraft, wind-power generation, and automobiles has not been achieved, and the composite industry has not yet formed a scale.

(5) The foundation of the structural–functional composite is weak, and comprehensive design methods for technical development are unavailable. The research facilities for reinforcement materials, resin matrices, functional fillers, and other raw materials are segregated. Low-level and homogenous competition is serious, and the material performance cannot meet the existing demands. New super materials, frequency-selection materials, graphene, and other new materials have recorded some progress in the field of structural materials with absorption and wave transmission. However, they are still in the stages of theoretical design and experiments in the laboratory, which is still far from the practical engineering application stage. Although China has made significant progress in the research on structure/wave absorbing composites, structure/bulletproof composites, and structure/heat resistant composites, the development of structural–functional composites still has limitations, such as lack of top-level designs, insufficient integration ability, insufficient technology sharing, repetition at a low level, vacancy in important fields, and insufficient interdisciplinary comprehensive design methods. The systems for the utilization, series, and standardization of materials have not been established, and the current high-performance products cannot be employed in the development of future technologies.

5 Development objectives and suggestions for high-performance polymer composites in China

5.1 Objectives and projects

5.1.1 Objective and projects for 2025

The objectives for 2025 regarding the development of high-performance polymer composites in China are as follows: the attainment of high-strength, high-strength medium-modulus, and high-modulus high-strength carbon

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fibers that satisfy the requirements of various applications and have industrial competitiveness. Significant advancement in large-scale para-aramid production and preparation technology is achieved, with the establishment of a 10000 t/a production line. Second-generation advanced composite materials based on high-strength medium-modulus carbon fibers are manufactured and applied on a large scale, with application potentials in large aircraft, manned space flight, and other major projects. These locally produced materials fully replace imported products in weapons and equipment, with the composite industry reaching the global advanced level.

The key development projects include the following.

(1) High-performance and low-cost preparation technology for domestic carbon fibers: achieving a manufacturing technology similar to that for the Toray T1100 carbon fiber, conducting stable engineering technology research on the M55J high-modulus and high-strength carbon fiber and on the key technology for the M65J level carbon fiber preparation, and realizing the application of the products in national defense projects. Achieving a domestic technology for preparing high-strength, high-modulus, and high elongation carbon fibers to fabricate composites characterized by high toughness, balanced compression, and tensile properties. The low-cost industrial preparation technology for T300-, T700-, and T800-grade carbon fibers in a scale larger than 1000 t and the integration technology of high-speed dry jet wet spinning should be developed. The key industrial technology for producing large tons of carbon fibers above 48 K also needs to be developed. (2) Large-scale integration of para-aramid production and preparation technology and building a 10 000-ton production line. (3) The design and application of carbon fiber composites in aerospace and other fields should be researched, including the design improvement and large-scale synthesis technique for resins with high-toughness prepreg matching that of the domestic T800 level carbon fiber, RTM resin formula design and large-scale synthesis technology, quality and performance consistency control technology of domestic high-strength medium-modulus carbon fiber prepreg, and RTM composite toughening technology. Fast manufacturing technology for composite materials and airworthiness verification technology for domestic high-strength medium-modulus carbon fiber composite materials. (4) Conduct researches on high-strength, high-modulus, high-toughness, and stretch/compression-balance carbon-fiber-reinforced resin matrix composite technologies. Third-generation advanced composites should be developed to fully replace high-performance aluminum alloys. (5) The application of domestic low-cost and high-performance polymer composites in construction, wind turbine blades, electrical cable lines, automobiles, and rail transportation should be realized.

5.1.2 Objective and projects for 2035

The objectives for 2035 regarding the development of high-performance polymer composites in China are as follows. Through independent innovation, high-performance reinforcement fiber technology and product series that meet the application requirements of China will be developed; sustained independent support capability of domestic high-performance fibers and their composites in national defense applications will be achieved. New high-performance fiber composite materials with applications in national advantageous industries, strategic industries, and new weapons and equipment will be developed, and the performance and market competitiveness of the domestic products will be improved through large-scale verification in the application environment. The industrialization and application of domestic high-performance polymer composites will be realized, promoting Chinese composite technology to the global stage to gradually surpass the leading countries.

The key development projects include the following. (1) The engineering manufacture of M55J, M65J, T1000, T1100, and other high-performance carbon fibers in accordance with the application requirements for national defense, the military industry, and national economic development is realized. (2) According to the requirements of the real service environment for material properties, the structural design of new high-performance resin matrices and the control of the ultrafine interfaces of polymer composites are realized; further, the development of new technologies, such as rapid prototyping of composite materials and integrated molding of super large composite materials, is realized. (3) A technology innovation system for the domestic polymer composite industry, which meets the requirements of major sectors, and for national defense and national economy applications, will be established.

5.2 Policy suggestions

5.2.1 Enhance independent innovation and promote the sustainable development of the industry

The development of high-performance polymer composites should be guided by the requirements of major fields and based on the promotion of scientific recognition. The process should focus on developing key technologies and achieving industrial innovation. It should not only focus on the urgent needs of national major projects, but also on the development of cutting-edge science and technology; additionally, it should eliminate the disconnection between production and application, and rapidly advance the industrial technology. A strict, scientific, and reasonable operational mechanism should be established.

5.2.2 Employ the requirements of advanced equipment as the stimuli for technological breakthroughs and promote industrial development through the demand scale of civil fields

Driven by the high performance and low cost of polymer composites, technological breakthroughs are achieved, and key strategic basic materials are guaranteed based on the demand for high-end products in aerospace and other national security fields. Additionally, the application in civil fields, including in automobiles, wind power, and pressure vessels, is expanded to enhance the creativity of the domestic industry. To realize the healthy and sustainable development of the domestic high-performance polymer composite industry, the requirements for application in national security, national defense modernization, national economy, and national medium- and long-term major projects should be satisfied.

5.2.3 Promote the construction of the high-performance polymer composite industrial chain, and establish high-efficiency and low-cost application technology systems

Emphasis should be laid on investment and guidance, and the layout for technical research based on the principle of "high-performance fiber reinforcement–composite material–market application system" should be strengthened. In addition, the foundation for development should be solidified. Focusing on cultivating the core strength of technology and equipment, a complete composite material design–manufacturing–application industrial technology chain should be built. The development of energy, transportation, construction engineering, and other important civil industries should be fostered, and a complete R&D industrial chain for producing high-performance fiber reinforcement, as well as high-performance resins and the application of composite materials, should be developed.

5.2.4 Cultivate professional talent, respect intellectual property and standardization construction, and support the construction of industrial innovation centers

To strengthen the integration of related disciplines, the scale of talent training should be expanded, and the training scheme of interdisciplinary talent should be improved. High-level open research platforms, such as enterprise technology centers and key laboratories, should be established in leading enterprises to strengthen and improve the technological level of the industry. Testing, process, and product quality standards should also be established. Intellectual property rights should be respected, and reasonable and orderly talent flow mechanisms should be established to promote independent innovation for the sustainable and healthy development of the high-performance polymer composite industry in China.

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