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Application of Graphene Materials in the Textile Field

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Abstract:
Graphene material is a new type of material with a two-dimensional planar nanostructure, which has been applied in multiple research fields due to its excellent optoelectrical and mechanical properties. This paper compares the differences between graphene materials and traditional materials through literature review; summarizes the research status of graphene-modified cellulose fibers, chemical fibers, and protein fibers in the textile field; and provides examples of the cutting-edge applications of graphene materials in smart textiles and functional textile products. The performance summary includes conductivity, UV resistance, bulletproofing, antibacterial properties, thermal insulation, etc. Combining graphene with textile materials can expand its application range in the civilian field, especially in high-performance fibers, new functional textiles, and smart textiles, where it has broad application prospects.

Keywords: Graphene, Fiber, Textile, Performance

1. Introduction

Graphene possesses ultra-high strength, excellent electrical and thermal conductivity, good light transmittance, and biocompatibility, making it highly promising for applications in the textile field. In recent years, the demand for textiles has not only been limited to daily wear and home decoration but has also placed higher requirements on the functionality of textiles. In addition to meeting ordinary value during use, textiles are also expected to have one or more functions such as conductivity, UV resistance, flame retardancy, hydrophobicity, and health benefits. Among these, graphene materials are widely used in the textile field due to their excellent electrical, optical, thermal, and mechanical properties.[1]

2. Introduction to Graphene

In 2004, an article published in Nature revealed the carbon structure of graphene as a thin film. Six years after the article was published, the 2010 Nobel Prize in Physics was awarded to the inventors of graphene technology[2]。

In 2004, physicists Andre Geim and Konstantin Novoselov from the University of Manchester successfully isolated graphene from graphite, proving that it can exist independently. Graphene is currently the thinnest, strongest, and most conductive and thermally conductive new nanomaterial, known as the “king of new materials.” Graphene is a two-dimensional crystal sheet with a hexagonal structure, tightly packed in a honeycomb lattice by single-layer carbon atoms. The carbon atoms are in SP2 hybrid orbitals, and the thickness of a single-layer graphene sheet is similar to that of a single-layer carbon atom, about 0.335 nanometers, making it one of the thinnest materials known. Current methods for preparing graphene include mechanical exfoliation, oxidation-reduction, thermal analysis, solvothermal, and chemical exfoliation. Graphene can be applied in important fields such as energy, aerospace, artificial intelligence, biomedicine, and national defense, as well as in civilian fields. Combining graphene with textile materials can expand its application range in the civilian field, especially in high-performance fibers, new functional textiles, and smart textiles, where it has broad application prospects[3].

2.1 Research Status

In 2011, Professor Gao Chao's research group[4]at Zhejiang University successfully spun macroscopic graphene fibers several meters long for the first time. The principle involves preparing graphene oxide liquid crystals through spontaneous orientation in a high-concentration graphene oxide aqueous solution, followed by wet spinning and chemical reduction to produce graphene fibers. Research shows that graphene fibers prepared by this method have excellent performance, but the spinnability of graphene as a standalone spinning solution is poor. To address this issue, a method was proposed to use ordinary spinning solutions as the matrix and add graphene dispersions to prepare graphene composite fibers. This approach not only improves the spinnability of graphene fibers but also fully utilizes the excellent properties of graphene materials in antibacterial, UV resistance, and far-infrared applications. This method will facilitate the better development of graphene fibers in the textile field.

Biomass graphene is a composite carbon material prepared from biomass (corn cob) cellulose as the raw material, loaded with metal/non-metal compounds, and referred to as biomass graphene. Biomass graphene not only possesses the high performance and multifunctional characteristics of graphene, but the presence of metal/non-metal compounds also significantly enhances the material's far-infrared, rapid temperature rise, and antibacterial properties. Biomass graphene comes in different specifications, including powder and slurry series. Shengquan Group has developed biomass graphene composite functional fibers and pioneered biomass graphene inner-warm fibers. They have overcome a series of challenges in biomass graphene composite fibers and spinning technology, establishing and optimizing processes for dispersion, pure spinning, blending, interweaving, knitting, and garment processing. To date, they have successfully developed a range of products, including biomass graphene inner-warm fibers, inner-warm fleece, composite functional fibers, fabrics, and apparel, forming a complete innovative industrial chain[5].

This material also found a series of applications during the Beijing 2022 Winter Olympics. During the Olympics, competitions and events were held in Beijing, Yanqing, and Zhangjiakou. At that time, the minimum temperature in Beijing was around minus ten degrees Celsius, while temperatures in Zhangjiakou and Yanqing were even lower, typically ranging from minus 20°C to minus 40°C day and night. Under such extreme cold conditions, conventional heating methods were insufficient to adequately protect staff and certain equipment. Therefore, graphene flexible heating materials were applied in the "Technology Winter Olympics" project. Products incorporating graphene flexible heating materials included scarves, vests, and gloves. Taking the scarf as an example, graphene material was embedded in the neck area beneath the surface of an ordinary scarf. A small button was placed at one end of the scarf, and pressing it for 3 seconds activated the heating function of the graphene. When the red light was on, the local temperature of the scarf could reach 55°C. The button also had two other temperature settings, indicated by green and blue lights, corresponding to 45°C and 35°C, respectively. The application settings for vests and gloves were essentially the same as those for the scarf. In this way, these products could rapidly generate heat and provide warmth in extremely cold environments[2].

Japanese researchers have combined graphene with aramid fabrics to produce composite materials with excellent thermal conductivity and bulletproof properties, applied in military and special occupational clothing. The Hohenstein Institute in Germany has developed a new graphene coating with strong flame retardancy and ultra-thin characteristics, ensuring flexibility and compressive strength in thermal protective clothing. The famous British off-road brand INOV-8, in collaboration with the University of Manchester, developed the first pair of sports shoes made from graphene material, named the "G series." The rubber outsoles of the "G series" sports shoes have been tested to be 50% stronger, more elastic, and more wear-resistant than those of ordinary sports shoes.

3. Comparison of Graphene Materials and Traditional Materials

The textile field, as a traditional and important industry, plays a crucial role in the development of human society. With technological advancements and the diversification of consumer demands, the textile field is undergoing profound changes. From traditional natural fibers to modern

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chemical fibers, and from single-purpose wear to multi-functional needs, the development of the textile field is rapidly evolving.

In today's society, a variety of materials are used in the textile field, each with its own characteristics to meet the needs of different textiles. Traditional materials used in the textile field include cotton, wool, silk, polyester fibers, etc. However, traditional textile materials mainly meet basic wear and decoration needs, and are lacking in functionality such as conductivity, flame retardancy, antibacterial properties, and thermal insulation. The performance improvement of textiles is limited by the inherent characteristics of fiber materials, making it difficult to achieve significant performance improvements through simple processes. The textile industry is a resource-intensive and environmentally polluting industry, with traditional textile processes using large amounts of harmful chemicals, causing environmental pollution.

Graphene Material: [3]In terms of mechanical properties, it has high tensile strength and good flexibility. It can withstand extremely large external forces without breaking and can return to its original state after bending and twisting. Regarding thermal properties, its thermal conductivity is as high as 5300 W/(m·K), with high heat dissipation or heat - gathering efficiency. The electrical properties are outstanding, with a carrier mobility of up to 200000 $cm^2/(V \cdot s)$, excellent electrical conductivity, and electromagnetic shielding performance. It has stable chemical properties, with characteristics such as anti - oxidation, anti - corrosion, antibacterial, and antiviral. It also has good breathability and moisture permeability. It is commonly applied in wearable electronic devices, functional clothing, and the medical field.

Cotton: It is soft and tough, with a breaking strength between 2.6 - 4.5 cN/dtex. It is prone to wear and deformation after multiple washes and wears. In terms of thermal properties, it has good moisture absorption, but a low thermal conductivity, and its heat preservation mainly relies on the air between the fibers. Its electrical property is good electrical insulation, but it is easy to generate static electricity in a dry environment. Chemically, it is resistant to alkali but not acid and is easily eroded by microorganisms. It has excellent breathability. It is usually used in the production of daily clothing and household items.

Wool: It is rich in elasticity, soft to the touch, with a breaking strength of 1.5 - 2.5 cN/dtex. Its wear resistance is average, and it is prone to pilling. It has an excellent heat preservation performance but poor heat dissipation ability. It is a poor electrical conductor and is easy to generate static electricity. It is resistant to acid but not alkali. It has a certain degree of breathability, but the air - permeation speed is slow. It is mainly used in the production of warm clothing and high - end clothing.

Silk: It has a relatively high strength, with a breaking strength of 3 - 4 cN/dtex. It has a soft and smooth texture, but poor wear resistance and is easily scratched. In terms of thermal properties, it has both heat - preservation and heat - dissipation functions, and its thermal conductivity is moderate. It is usually an electrical insulator and is easy to generate static electricity under specific conditions. It has good chemical stability but is not resistant to strong acids, strong alkalis, and some organic solvents. It has good breathability, but it dries slowly after absorbing moisture in a high - humidity environment. It is often used in the production of high - end clothing and home decorations.

Polyester Fiber: It has high strength, with a breaking strength of 4 - 7 cN/dtex. It has good elastic recovery, is not easy to deform, and has outstanding wear resistance. It has poor moisture absorption, making it stuffy to wear, and its heat preservation depends on the thickness and structure of the fabric. It has good electrical insulation and is easy to generate static electricity. It has excellent chemical stability, is resistant to acids, alkalis, and organic solvents, and is not easy to mildew or be damaged by insects. Ordinary polyester fiber has average breathability, and its breathable performance can be improved after special treatment. It is often used in the manufacturing of sportswear and outdoor equipment.

4. Modification of Graphene Materials

The emergence of graphene has provided a new approach to modifying traditional materials. The combination of graphene with traditional textile fibers through composite modification has significantly expanded the application space of graphene in the textile field. Graphene-modified fibers exhibit good spinnability and can be blended or interwoven with various types of fibers while retaining the low-temperature far-infrared, antibacterial, and antistatic properties of graphene. This makes them more widely and conveniently applicable in clothing, home textiles, and other fields[6].

4.1 Graphene-Modified Polyester Fibers

Polyester fibers (polyester) are widely used in the apparel and industrial sectors due to their simple manufacturing process, good elasticity, chemical stability, high abrasion resistance, strong corrosion resistance, insulation, stiffness, and quick-drying properties. However, as living standards improve, consumer demands for clothing have shifted beyond durability and comfort to include functionality and health benefits. As a result, researchers have turned to graphene to modify polyester fibers, endowing them with unique functional characteristics.

Wang Shuangcheng et al. prepared graphene-modified polyester fibers using renewable biomass graphene powder and polyester powder through melt spinning. Tests showed that the far-infrared emissivity of the fiber reached 0.92, and the far-infrared irradiation temperature rise was 5.5°C, both exceeding the standards specified in GB/T30127 "Testing and Evaluation of Far-Infrared Properties of Textiles." Additionally, the antibacterial rates of the fiber against E. coli and Candida albicans exceeded 99%, far above the standard requirements, indicating significant antibacterial effects. Quilts filled with this fiber had similar warmth retention to down but with more than eight times the breathability of down [7].

4.2 Graphene-Modified Cellulose Fibers

Cellulose fibers are one of the most common textile raw materials, favored by consumers for their excellent moisture absorption, breathability, softness, and comfort. Similar to bamboo charcoal fibers, graphene/cellulose fibers also exhibit superior antibacterial properties. Chi Shuli's team prepared composite fibers by adding different proportions of graphene to cellulose spinning solutions, finding that the electrical conductivity of the fibers was positively correlated with the graphene content. Guan Jie [8] and colleagues studied the antibacterial properties of cellulose fibers doped with varying graphene contents. They discovered that as the graphene content increased, the antibacterial properties of the fibers gradually improved. When the graphene content reached 0.285%, the antibacterial performance met national standards. Additionally, the antibacterial effect remained unchanged after washing, demonstrating excellent antibacterial durability.

4.3 Graphene-Modified Protein Fibers

Protein fibers have attracted widespread attention due to their convenient sourcing and smooth texture. In experiments applying graphene to modify protein fibers, researchers found that graphene-modified protein fibers not only enhanced basic properties such as wear resistance and durability but also made significant progress in functional aspects like antibacterial performance, UV resistance, and waterproofing. Wang Shudong [9] and colleagues used an impregnation method to prepare graphene-modified protein fibers by integrating graphene oxide materials onto the surface of silk fibers. Tests revealed that the UV resistance of the silk fabric was significantly improved.

4.4 Graphene-Modified Viscose Fibers

Wang Shuangcheng investigated the properties of graphene-modified viscose fibers with a graphene content of 2.5%. It was found that the fibers exhibited poor toughness, brittleness, and were prone to damage during spinning. However, they demonstrated excellent antistatic properties. The addition of graphene reduced the surface resistivity of the fibers, imparting a certain level of surface lubricity and lowering the friction coefficient, thereby inhibiting and reducing the generation of static charges [10].

4.5 Application Analysis of Graphene-Modified Fibers

Modifying fibers with graphene can impart numerous superior properties, such as high strength, good toughness, lightweight, fast electrical and thermal conductivity, and even functionalities like antibacterial, anti-mite, and low-temperature far-infrared heating. As a result, graphene-modified fibers are widely applied across various fields [11].

Graphene has extremely high strength and modulus, and adding it to fibers can significantly improve their tensile strength, abrasion resistance, and tear resistance. For example, in making sportswear and outdoor gear, graphene-modified fibers can make products more durable, withstand greater external forces, and extend their service life. Utilizing graphene's far-infrared emission, antibacterial, and antistatic properties, modified fibers can endow clothing with warmth, antibacterial, and antistatic functions. For instance, thermal underwear made with graphene-modified fibers can better retain body heat; underwear and socks made with this fiber can effectively inhibit bacterial growth and reduce odors. The addition of graphene can improve the moisture-wicking properties of fibers, allowing skin surface moisture to be quickly expelled, making the wearer feel drier and more comfortable. At the same time, the softness and feel of the fibers may also be improved, enhancing the wearing experience of the clothing.

5. Excellent Properties of Graphene Fabrics

The structure of graphene is very stable, and to date, researchers have not found any missing carbon atoms in graphene. The connections between carbon atoms in graphene are very flexible, and when external mechanical force is applied, the carbon atom plane bends and deforms, allowing the carbon atoms to adapt to the external force without rearranging, thus maintaining structural stability. This stable lattice structure gives carbon atoms excellent conductivity. The excellent conductive properties of graphene can be applied to textiles to produce excellent antistatic or conductive fabrics. For example, soaking polyester fabrics in a graphene oxide solution and then

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reducing them can significantly improve the conductivity of the modified polyester fabrics, and their electrochemical properties are greatly improved compared to untreated polyester fabrics[12].

Graphene has excellent antibacterial properties, is almost non-toxic to cells, and can form a protective barrier on the skin surface, effectively resisting bacterial invasion. Compared to traditional inorganic and organic antibacterial agents, graphene is more skin-friendly and has significant advantages. Based on these properties, adding graphene to fabrics can endow them with antibacterial functions, providing great application value[4].

Graphene has excellent electrical conductivity, with a resistivity of about 10^-6 Ω·cm, making it the material with the lowest known resistivity. Therefore, combining it with fabric surfaces can endow fabrics with excellent conductive properties, suitable for flexible wearable electronic products[1].

6. Challenges and Prospects of Graphene Applications

Although graphene has many benefits in the textile field, the functional research on graphene is still mainly laboratory-based, and there are some difficulties in applying it directly to mass production.

6.1 Preparation Technology Challenges

Currently, there are various methods for preparing graphene, such as mechanical exfoliation, chemical vapor deposition (CVD), and oxidation-reduction. However, these methods face challenges in achieving large-scale, high-quality graphene production. Mechanical exfoliation produces high-quality graphene but with very low yield, making it difficult to meet industrial production needs. CVD can produce large-area, high-quality graphene, but the equipment is expensive, the process is complex, and impurities are easily introduced during growth. Oxidation-reduction has relatively low costs and can achieve a certain scale of production, but the graphene produced has many defects, affecting its performance[8].

Graphene produced by different methods varies greatly in terms of layer number, size, and defect degree. Even with the same method, the quality between batches is difficult to guarantee consistency. This instability in quality makes it difficult to achieve standardization and large-scale production of graphene, limiting its application in fields that require high consistency in material performance.

The preparation process of graphene is not yet mature, resulting in high production costs, poor quality, and low yield. Due to the low adsorption of graphene on substrates, its functionality cannot be fully demonstrated. Therefore, improving the preparation process to increase graphene material yield and reduce costs, making it widely marketable, is an important research direction in the future.

6.2 Application Compatibility Issues

When applying graphene to existing material systems or products, compatibility issues often arise. For example, in composite materials, the interfacial bonding force between graphene and the matrix material is insufficient, leading to insignificant or even reduced performance improvement of the composite material. In electronic device applications, the integration process of graphene with traditional semiconductor materials is not yet mature, affecting the performance and stability of the devices.

Currently, there is a lack of unified quality standards and testing methods for graphene in various application fields. This makes the quality of graphene products produced by different enterprises uneven, making it difficult to conduct effective quality evaluation and comparison. At the same time, it also brings difficulties to the market promotion and application of graphene products, causing concerns for customers when choosing and using graphene products.

7. Conclusion

The application of graphene materials in the textile field has brought significant performance improvements and functional innovations to textile products. From enhancing the basic properties of fabrics to endowing them with special functions such as antibacterial, antistatic, and electromagnetic shielding, and promoting the development of smart textiles, graphene has shown great application value. However, the application of graphene in the textile field still faces some challenges, such as high preparation costs, the need for improvement in large-scale production technology, and further optimization of compatibility with textile materials. With the continuous advancement of science and technology, it is believed that these problems will be gradually solved, and the application prospects of graphene in the textile field will be broader, potentially driving a new round of technological transformation and industrial upgrading in the textile industry.

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