

# Research on the Application of Nanomaterials in Textile Field

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## ABSTRACT

Nanomaterials, due to their unique properties, have shown great potential in the textile industry, significantly enhancing functionality, comfort, and intelligence. However, their application still faces technical challenges and safety concerns. This study reviews the significant applications of nanomaterials in textiles, emphasizing that through technological innovation and standardization, nanotextiles can achieve more efficient functionality and environmental friendliness, bringing greater convenience to human life. Future research should focus on developing multifunctional textiles, establishing standards, and improving safety evaluation systems to promote the healthy development of the textile industry.

## KEYWORDS

Nanomaterials; Textile field; Application; Function; Comfort; Textile development

## 1. INTRODUCTION

Nanomaterials are materials with unique properties and structures. They are called nanomaterials because they have a dimension of 1 to 100 nanometers in at least one direction. These materials exhibit distinct properties in optics, mechanics, electricity, and chemistry compared to other materials. Based on their composition, nanomaterials can be categorized into metallic nanomaterials, non-metallic nanomaterials, and composite nanomaterials.

In today's world, the global textile industry is undergoing significant changes, primarily characterized by textiles becoming more functional and sustainable. This shift also demands a high level of innovation in materials. Additionally, textiles are increasingly being used in specialized applications such as outdoor, military, and medical settings, where these areas require materials with high strength and heat resistance. Therefore, research into nanomaterials can significantly enhance the functionality and versatility of textiles.

Due to their small size, low specific surface area, and quantum effects, nanomaterials can transform traditional textiles from basic functions like 'insulation and protection' into multifunctional, high-performance, and intelligent products. For instance, nanodevices like conductive materials can integrate textiles with smart technology, enabling features such as heart rate monitoring. Additionally, nanoluminescent materials can be used for night safety signs, offering vast potential in the textile industry that awaits further exploration.

In the future, by incorporating nanomaterials, people may no longer have to worry about their clothes smelling bad, as materials like nano-silver can effectively kill bacteria over time. Additionally, when people fall while hiking outdoors, their clothes will be less likely to tear, thanks to graphene and other nanomaterials, making them more durable and safer to wear. Furthermore, due to industrial pollution, environmental concerns are likely to rise sharply in the future. However, these nanotextiles can

naturally degrade and, through green manufacturing processes, significantly reduce chemical usage, thus achieving environmental goals to some extent.

The application of nanomaterials in the textile industry is driving a technological revolution, endowing traditional textiles with unprecedented functionality, comfort, and intelligence. This article aims to review the significant advancements, representative applications, and challenges of nanomaterials in the textile sector from multiple perspectives, exploring broader future applications of nanomaterials in the textile industry.

## 2. LITERATURE REVIEW

In the article "Application of Nanomaterials in Textiles (2024)" [1], Gao Yanyuan mentioned that nanomaterials, with their unique properties, can significantly enhance the functionality of textiles. These enhancements include improving mechanical properties such as tensile strength, tear resistance, elastic modulus, wear resistance, and antibacterial, deodorizing, and UV protection. The rational use of nanomaterials is a crucial approach for innovation and development in the textile industry. With advancements in nanotechnology, smart textiles equipped with electronic components and sensors can monitor physiological indicators, promote wound healing, and achieve one-way moisture absorption and sweat wicking.

In the study on the application of nanomaterials in textiles (2021) [10], Gao Jianping explored the characteristics, specific applications, and limitations of nanomaterials. By integrating with traditional textile raw materials, nanomaterials endow textiles with a variety of new functions to meet different needs. These textiles include antibacterial and deodorizing textiles

Ultraviolet shielding fabrics, electromagnetic radiation shielding fabrics, antistatic fabrics and other functional fabrics (such as luminescent fibers and flame retardant fibers). Although nanomaterials show many advantages in textiles, their practical application still faces some technical obstacles: such as

**Dispersion problem:** Due to the small grain size and high surface energy of nanomaterials, agglomeration is easy to occur, which makes it difficult to disperse evenly on the surface of spinning or fiber.

**Polar difference problem:** there is a polar difference between some nanomaterials and spinning solution, which is easy to occur in uneven phenomenon during mixing, affecting the fluidity and spinnability of spinning solution.

**Insufficient bonding strength:** the bonding between nanoparticles and fiber textile is not strong enough, which reduces the stability and durability of textile products. Contemporary research in overcoming technical obstacles:

Synthesize nanomaterials in situ within or on the surface of fibers, utilizing the porous structure of fibers to address agglomeration issues and enhance the bonding between nanomaterials and the fiber matrix. Modify the fiber surface by chemically etching or plasma treatment to increase roughness, enhance the number of active groups, and improve the bond strength.

The surface of nanomaterials was coated and modified by graft polymerization reaction or gel-sol method to improve their binding ability with fibers.

**Formulating standards and strengthening research:** As a new technology, nanotechnology has broad application prospects in the textile industry.

In the article "The Development and Application of Textile Technology" (2015) [6] by Duomen Lin and Zhang Linzi, they explore the application and development of nanomaterials in textiles, analyzing their technical advantages, potential risks, and market prospects. This research provides theoretical support for the development of functional textiles. The article highlights the significant market

demand for nanotextiles and suggests future research directions, including the development of waterproof, oil-resistant, UV-protective, and antibacterial functional textiles, as well as color-changing and heat-resistant clothing, indicating a broad and promising future.

### 3. THE CORE APPLICATION FIELD OF NANOMATERIALS

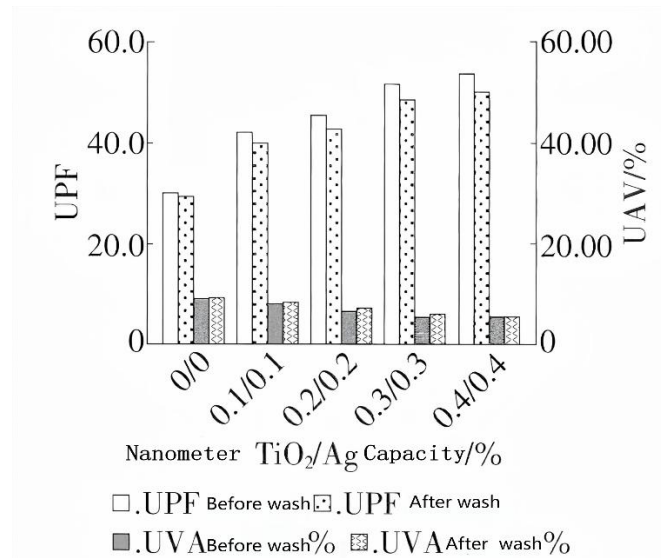
#### 3.1. Antibacterial Protection

Most organic antibacterial and deodorants have the disadvantages of poor heat resistance, easy to volatilize, easy to decompose and produce harmful substances, and poor safety. Therefore, people actively develop and research inorganic antibacterial and deodorants. Antibacterial and deodorants based on nano TiO<sub>2</sub> are widely used in textile fibers.

The excellent antibacterial activity of silver nanoparticles is crucial for inhibiting bacterial growth on fabric surfaces, preventing the spread of pathogens, and protecting fabrics from bacterial-mediated damage. Surface modification and fabric finishing methods can effectively coat the fabric surface with antibacterial nanoparticles, reducing their migration in the environment and maintaining long-term antibacterial effects. In recent years, silver nanoparticles have been widely used in medical textiles, gloves, bandages, and socks to inhibit bacterial growth. Xia Yong et al. [4] prepared a silver nanoparticle/polyurethane composite fiber membrane using electrospinning technology and studied the antibacterial performance of the nanofiber membranes with different silver loading levels. The results showed that as the silver loading increased, the antibacterial performance also improved. When the silver loading was 300 $\mu$ L, the antibacterial rate against both *Escherichia coli* and *Staphylococcus aureus* reached over 99.99%.

Zinc oxide nanorods: can enhance mechanical durability and broad spectrum antibacterial properties (inhibition rate of H1N1 virus is 95%).

UV Protection (UPF50+): One of the key advantages of nanomaterials is their UV protection capability. These materials are composed of various substances that have been broken down into micron or even nanometer-sized particles. Many of these components, such as MgO, ZnO, SO<sub>2</sub>, CaCO<sub>3</sub>, metals, and kaolin, when crushed into micron or nanometer-sized powders, have a larger specific surface area and higher surface energy compared to light waves of the same or shorter wavelength. This results in high compatibility between the ultrafine powders and polymers when mixed. For example, titanium dioxide (TiO<sub>2</sub>) nano-coatings (particle size <50 nm) can increase the UPF value to over 200, as seen in Coolibar sun-protective clothing. Reflective, scattering, and absorption are the primary mechanisms by which textile materials protect against UV radiation. By applying special finishing methods to attach nanomaterials to the fiber surface, the two-dimensional structure and surface effects of these materials can continuously reflect, scatter, and absorb UV rays, thereby enhancing UV protection. Zhang Hui et al. [7] developed a nano-titanium dioxide silver composite aqueous temperature-sensitive polyurethane (TiO<sub>2</sub>Ag-WTSPU) emulsion using an in-situ loading method and applied it to fabric finishing. The UV protection coefficient (UPF) of the fabric before and after finishing and washing is shown in Figure 1, with a UV protection coefficient (UPF) of 53.7 and a long-wave UV transmission rate (UVA%) of 4.96%. The results indicate that the fabric's UV protection performance has been significantly enhanced after finishing.



**Figure 1.** UV resistance effect before and after fabric finishing and washing

### 3.2. Nano Antistatic Agent

Synthetic fiber clothing and carpets, due to the generation of static electricity, are prone to dust accumulation and contamination. Some operating platforms and venues are particularly vulnerable to explosions caused by static sparks. Nanotechnology can address the static electricity issue in textiles. For instance, adding 0.1% to 0.5% of semiconductor particles like nano-TiO<sub>2</sub>, Cr<sub>2</sub>O<sub>3</sub>, ZnO, and Fe<sub>2</sub>O<sub>3</sub> to resins can create excellent anti-static shielding. This can reduce the surface resistance of the products to 10<sup>8</sup> to 10<sup>9</sup>Ω, significantly enhancing the safety factor against static electricity. When certain nano-particle composites are combined with high molecular synthetic fibers, they exhibit strong absorption in the mid-infrared band, providing excellent shielding.

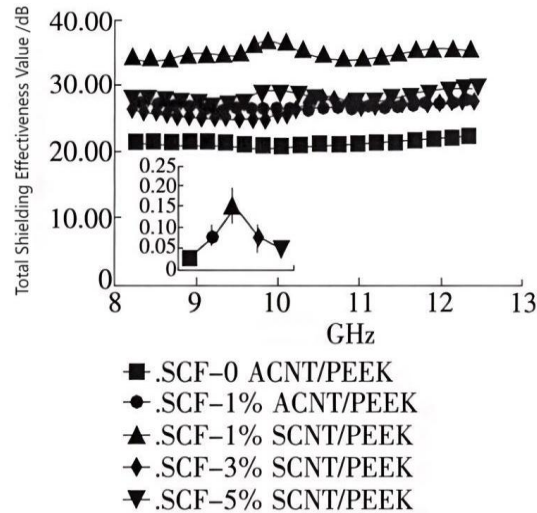
### 3.3. Nano Infrared Absorption Material

When far-infrared nanotextiles absorb the body's far-infrared energy, their temperature rises, increasing the total power of the infrared radiation they emit. This warming effect on the skin is beneficial for the human body. The warming effect of far-infrared nanotextiles stimulates the skin, reducing vascular tension and promoting capillary dilation, which enhances microcirculation and improves both local and systemic blood circulation. Research indicates that textiles treated with far-infrared nanotechnology can induce molecular resonance in human cells, generating a thermal effect and activating surface cells. This process promotes microcirculation in the subcutaneous tissue, achieving benefits such as warmth, health maintenance, enhanced metabolism, and improved immunity.

### 3.4. Magnetic Shielding Fabric

Electromagnetic shielding materials primarily function by reflecting or absorbing electromagnetic waves, with the absorption of electromagnetic waves not causing secondary pollution. This method is more environmentally friendly than reflecting electromagnetic waves. Moreover, wave-absorbing textiles offer several advantages: they are lightweight, have excellent wave absorption properties, are easy to bend and cut, and are non-toxic and eco-friendly. These materials have already found applications in the military sector. Due to their large specific surface area, electromagnetic waves entering nanomaterials can easily cause conduction loss, high-frequency dielectric loss, and hysteresis loss, converting electromagnetic energy into heat. This leads to the decay of electromagnetic wave signal energy, achieving the effect of electromagnetic shielding. Qu Mingcheng et al. [5] prepared continuous carbon fiber reinforced polyether ether ketone composites

with different components of carbon nanotubes (CNTs). They characterized the electrical conductivity and electromagnetic interference shielding performance of these composites. The results are shown in Figure 2. Adding an appropriate amount of CNTs can enhance the electromagnetic shielding performance of the laminate. The laminate with 1% sizing CNTs can achieve an average value of 34.97dB in the 8~12 GHz band.



**Figure 2.** The total shielding effectiveness values of laminated plates composed of different CNT components

Ruan Jing et al. [2] developed silicon carbide ceramic matrix composites. The electromagnetic shielding efficiency of porous silicon carbide nanowire preforms increased from an average of 9.2 dB at the X-band to 64.1 dB, demonstrating significant potential for application in next-generation military electromagnetic shielding materials. Kausar et al. [3] investigated the electromagnetic shielding performance of polyaniline/graphene nanosheet nanocomposites with varying graphene nanosheet content. Their study revealed that the addition of 10% graphene nanosheets resulted in over 95% improvement in electromagnetic interference (EMI) shielding efficiency across the X-band spectrum.

### 3.5. Flame Retardant Fabrics

Textiles are flammable, making the development of flame-retardant textiles particularly important. In recent years, the rise of nanotechnology has sparked a trend in the production of flame-retardant textiles. Introducing carbon nanotubes, graphene, and other nanomaterials into the fibers or on their surfaces can enhance the flame retardancy and conductivity of textiles. These nanomaterials can be used alone or in combination with other additives, and even in conjunction with other additives to develop new flame retardants. Liu et al [8] prepared a polyester fabric (CAB-PL) coated with a calcium alginate and nano-calcium borate composite material using a post-crosslinking method. The fabric's flame retardancy and thermal stability were evaluated using the Limit of Oxygen Index (LOI) and thermogravimetric analysis. The results showed that the LOI value of CAB-PL was 34, significantly higher than that of polyester fibers, indicating that CAB-PL is more difficult to ignite. Thermogravimetric analysis indicated that the presence of the surface-coated composite material resulted in more char and effectively inhibited heat conduction. Additionally, the LOI value of the polyester fabric coated with the calcium alginate and nano-calcium borate composite material was significantly higher than 27, indicating that it can be considered a reliable flame-retardant material. Zhang et al [9] prepared functional silk fabrics with enhanced flame retardancy and smoke suppression using magnesium hydroxide ( $Mg(OH)_2$ ) nanoparticles. The study found that the higher the concentration of the nano- $Mg(OH)_2$  used, the better the flame retardancy of the coated silk. The nano-magnesium hydroxide primarily improved the flame retardancy of the silk fabric. When the nano- $Mg(OH)_2$  concentration was 0.25 and 0.50 mol/L, the carbonization lengths of the coated

samples decreased from 30.0 cm of the original silk to 9.4cm and 8.6 cm, respectively. The LOI value of the silk fabric was 24.4%, indicating that nano-magnesium hydroxide has a good flame-retardant effect on silk.

#### **4. BREAKTHROUGH IN KEY TECHNOLOGIES**

In today's rapidly evolving textile industry, the development of functional textiles using nanomaterials as additives has become a key focus. However, uncertainties regarding nanomaterial toxicity and their inherent uncontrollability have hindered standardization efforts for nanomaterial-modified functional textiles, directly impacting their development. To effectively utilize nanomaterials in this field, we must overcome technical limitations while establishing standards and adopting advanced technologies. The author proposes the following approaches to explore viable improvements:

In view of the technical obstacles in the application of nanomaterials in the field of textiles, in order to ensure the application effect of nanomaterials and promote the transformation and upgrading development of the textile industry, we should start from the following three aspects according to the specific technical obstacles to overcome the technical obstacles in the application of nanomaterials.

Synthesize nanomaterials in situ on the surface or inside of the fiber. The principle of this method is to make full use of the characteristics of the porous structure of the fiber material, solve the problem of agglomeration of nanomaterials in mixed use, and make the nanomaterials uniformly mixed with the fiber matrix, which is conducive to improving the bonding degree between the nanomaterials and the fiber matrix.

For the surface modification of fibers, chemical etching, plasma treatment and other methods can be considered to roughen the surface of fibers, so as to increase the data of active groups and make the fiber matrix and nanomaterials firmly combined together.

Surface coating and modification of nanomaterials, based on graft polymerization reaction, gel-sol method, etc., surfactants, super dispersant and other coating modification reagents are used to improve nanomaterials, so as to effectively improve the binding ability of nanomaterials and fibers.

In the field of textile application of nanomaterials, it is necessary to deal with the problems in the application technology, and also to focus on other problems in the application of nanomaterials, such as the toxicity of nanomaterials, the characteristics of nanomaterials, etc., which requires relevant personnel to do a good job in the formulation of standards for nano-functional textiles and technical application.

Establish standards for nano-functional textiles. Due to their health benefits, UV protection, antibacterial properties, and deodorizing capabilities, these textiles have gained significant market recognition and popularity among consumers. However, a few merchants, driven by the desire for huge profits, have intensified the hype around nano-materials, leading to the use of inferior products and severely disrupting the market for nano-functional textiles.

The order of the nanotechnology textile industry should be maintained to ensure its sustainable and healthy development. To address this issue, it is necessary to further regulate the textile market, enhance the performance testing of nano-functional textiles, and establish and refine standards for nano-modified functional textiles. Furthermore, to ensure the feasibility and effectiveness of these standards, it is essential to dynamically optimize and improve them based on practical considerations when setting the standards for nano-modified functional textiles.

The development of new nanomaterials, along with advancements in textile technology, microelectronics, and nanotechnology, has provided the necessary technical support for the advancement of nano-modified functional textiles. Given the rapid development of advanced technologies such as intelligent technology, it is crucial to accelerate the research and development

of intelligent fibers. This will enable the continuous creation of more multifunctional and high-value-added modified functional textiles, thereby promoting the healthy and sustainable growth of the textile industry.

Due to the unique small size effect of nanomaterials, while their application in the textile industry can enhance people's well-being, it also poses certain risks to human health and the environment. Currently, research on the biological effects of nanomaterials has led to the emergence of a new interdisciplinary field known as nanotoxicology. However, this field is still in its early stages of development. To ensure the safe use of nanomaterials in textiles, it is crucial to accelerate the establishment and improvement of effective evaluation methods, develop a safety assessment system and testing standards for nanomaterials, and support the development and utilization of these materials.

## **5. BOTTLENECKS AND CHALLENGES**

While nanotechnology has opened up many opportunities for the textile industry, as with any new technology, it also poses potential risks. These risks have not yet been quantified, but it is necessary to take preventive measures against them and understand the current and future environmental, health, safety, ethical and social impacts of nanotechnology.

Nano-materials textiles have more functions, but there are still many limitations in practice, which makes it difficult for nano-materials to help the transformation and upgrading of textile products. The author believes that the main obstacles of nano-materials applied in textiles include the following points.

Nanoparticles are often difficult to disperse uniformly on the surface of fibers during spinning, typically distributed in an uneven manner. This is primarily due to the grain size of nanomaterials ranging from 0.1 to 100nm, which not only has a high surface energy but also tends to aggregate easily. As a result, nanoparticles struggle to disperse evenly on the fiber surface, making it challenging for nanomaterial applications to meet the practical needs of fiber clothing.

There is a polarity difference between part of the nanomaterials and the spinning solution. Once the nanomaterials and spinning solution are mixed, there will be an uneven mixing phenomenon of the nanoscale particles and spinning solution, and there will be a phenomenon of agglomeration of nanoscale particles, which directly affects the fluidity and spinnability of the spinning solution.

The bonding strength between nanoscale particles and fiber textiles is insufficient to meet the requirements, resulting in a lack of high stability and durability in textiles. Therefore, when applying nanomaterials in textile production, it is crucial to enhance the bonding between nanomaterials and fibers to ensure the effectiveness of nanomaterials and produce high-quality fiber textiles.

There is evidence that some materials are toxic when made into nanoparticles, possibly due to their large specific surface area. A proper understanding of the properties of nanomaterials is essential to help relevant professionals and the public avoid risks associated with exposure to these substances. Research on the potential environmental and human health risks posed by nanomaterials focuses on the following key issues:

Adsorption of nanomaterials on skin and toxicity of nanomaterials to skin;

Compared with other water source pollutants, whether nanoparticles are toxic and how they act as toxins after entering drinking water;

Study on the effect of nanoparticles on lung tissue of operators;

Environmental effects of nanoparticle deposits in marine or freshwater waters;

Under what conditions nanoparticles may absorb and release environmental pollutants.

## **6. FUTURE TRENDS AND DEVELOPMENT DIRECTIONS**

The development of nanotechnology has opened up a new micro world for human beings, and the development of nanotechnology will strongly promote the development of functional textile technology to high-tech fields. In addition to the above application areas, the following developments will be very attractive:

At present, nanofiber and conductive polymer fiber with good electrical conductivity can be manufactured. These fibers are used in electronic circuits or artificial muscles, which will help promote the miniaturization of electronic devices and promote a deeper understanding of bionic technology.

Nanofibers are used in super electrodes and super catalyst carriers, which can be expected to greatly improve the efficiency of electrodes and catalysts.

Using the special properties of nanomaterials, such as enhancement, toughening and superabsorption, to develop functional textiles with higher performance and stronger strength. The United States is studying the special absorption and dispersion of impact energy by nanodiameter fiber fabrics to develop super bulletproof vests

The combination of nanotechnology with light absorption technology or dye manufacturing technology to develop green textiles to meet environmental protection requirements,

As the application of nanotechnology continues to mature, nanomaterials will increasingly be integrated into functional textiles. These materials are versatile and lightweight, with excellent breathability, offering significant advantages over traditional textiles. Future research in nanotextiles aims to incorporate various nanotechnologies into the textile industry, leading to the creation of textiles with diverse functionalities. In addition to being waterproof, oil-resistant, UV-protective, and antibacterial, these textiles could also feature magical color-changing properties and heat-resistant features. These advancements represent the promising future of nanotechnology in the field of functional textiles.

## **7. SUM UP**

This research systematically reviews the latest research progress of nanomaterials' application in the textile industry, focusing on their potential in enhancing functionality, comfort, and intelligence. At the same time, it deeply analyzes the current technical obstacles, such as the dispersion of nanomaterials, the firmness of bonding with the matrix, and safety challenges. Based on this, it proposes future research directions. In terms of application areas, it mainly covers antibacterial protection (studies show that the antibacterial rate of silver nanoparticles can reach 99.99%), UV protection (such as titanium dioxide nanomaterials significantly increase the UV protection coefficient UPF value of the fabric), and anti-static performance (such as specific nanoparticles can effectively reduce the surface resistance of the textile). Key technical breakthroughs involve in-situ synthesis on the fiber surface, surface modification treatment, and nano-material coating modification. The main technical bottlenecks include the dispersion problem of nanomaterials in the textile matrix, compatibility difficulties caused by polarity differences between materials, and insufficient bonding firmness between nanomaterials and fibers. Future development trends focus on the development of new functional nanomaterials, research on green and environmentally friendly preparation processes, and the design and manufacture of multi-functional integrated intelligent textiles. The research conclusion indicates that nanomaterials have significant advantages in enhancing the functionality and comfort of textiles. However, key technical obstacles need to be overcome to promote the transformation of the textile industry towards high-performance and environmentally friendly directions.

## REFERENCES

- [1] Gao Yanyuan. Application of Nanomaterials in Textiles [J]. *Chemical Fiber & Textile Technology*, 2024, 53(12): 14 - 16. DOI: 10.3969/j.issn.1672 - 500X.2024.12.005.
- [2] Ruan Jing, Yang Jinshan, Yan Jingyi, et al. Electromagnetic shielding performance of silicon carbide ceramic matrix composites reinforced by three-dimensional silicon carbide nanowires (English) [J]. *Journal of Inorganic Materials*, 2021, 37(5):579-584.
- [3] KAUSAR A. Polyaniline/graphenenanoplatelet nanocomposite toward high-end features and application [J]. *Materials Research Innovations*, 2021, 26(4):249-261.
- [4] Xia Yong, Feng Jundan, Xu Sijun et al. Preparation and properties of electrospun nano-silver/polyurethane composite films [J]. *Dyeing and Finishing*, 2022, 48(4):54-57.
- [5] Qu Mingcheng, Zhang Liying, Zhou Jianfeng et al. Mechanical and electromagnetic shielding properties of carbon nanotube-modified CF/PEEK composites [J]. *Journal of Composite Materials*, 2021, 39(7):3251-3261.
- [6] Duomen Lin, Zhang Linzi. Development and Application of Nanofiber Textile Technology [J]. *Liaoning Silk*, 2015(4): 28-29, 45. DOI: 10.3969/j.issn.1671-3389.2015.04.011.
- [7] Zhang Hui, Zhou Ting, Wang Yuanyuan, et al. Application study of nano-TiO<sub>2</sub> composite aqueous thermosensitive polyurethane finishing agent [J]. *Journal of Hunan Institute of Engineering: Natural Science Edition*, 2021, 31(3):73-77.
- [8] LIU Z, LI J, ZHAO X, et al. Sur-face coating for flame retardancy andpyrolysis behavior of polyester fabricbased on calcium alginate nanocompos-ites [J], *Nanomaterials*, 2018, 8(11):875.
- [9] ZHANG C, CHENG XW, GUAN JP, et al. Preparation of nanoMg(OH)<sub>2</sub> for surface coating of silk fabric with improved flame retardancy and smoke suppression [J]. *Colloids and Surfaces a Physicochemical and Engineering Aspects*, 2021(625):126868
- [10] Gao Kanping. Research on the Application of Nanomaterials in Textiles [J]. *Chemical Fibers & Textile Technology*, 2021, 50(9): 20-22. DOI: 10.3969/j.issn.1672-500X.2021.09.010.