Development and Application of Infrared Radiation Materials in the Field of Textile and Clothing

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Abstract: In this paper, a review of the development of infrared radiation materials and preparation methods in the field of functional textiles is conducted, focused on the introduction of technologies used for the development and preparation of infrared radiation functional textiles. Four kinds of functional textiles with far-infrared, infrared radiation refrigeration, infrared radiation heat preservation and infrared radiation heat regulation separately are emphasized. On this basis, the prospects of development and application of infrared radiation materials in the field of textile and clothing are discussed.

1. Introduction
Since the discovery of infrared rays, the research on the infrared radiation materials has drawn the attention of scientists around the world and the applications of the infrared radiation materials have covered a variety of fields[1,3]. Up to now, lot of materials which are beneficial to humankind lives or production activities have been found. For example, the full spectral emissivity of the coating with La-doped CeO₂ at 600 °C is about 0.9, which can be used to enhance the heat dissipation of the aircraft in ultra-high speed flight[4]. Furthermore, some researchers have found that some infrared radiation materials have medical and nutrition value which can inhibit the growth of tumor cells and promote blood flow[5,6]. In addition, adjusting the infrared emissivity of the materials has been demonstrated to have the potential for energy conservation in buildings[7]. This paper describes commonly development and application of infrared radiation materials in the field of textile and clothing.

2. The development of infrared radiation functional textiles

2.1. Development of far-infrared textiles
Far-infrared textiles were first developed by Japanese researchers and then researchers from European, American, China and other countries have carried out quite a lot of work and achieved a lot of success in this field[8]. The focus of these research works is to enhance the material infrared emissivity in 8-14 μm wavebands. Combining the inorganic powder with fibers, fabrics or other textile products is one of the most widely used methods[9]. The summary of some inorganic powder which used to increase infrared emissivity of textiles have been presented, as in table 1.
Besides, the particular focus of some researchers is the mechanism of the health care function of the far-infrared textiles. Ian L Gordon [14] organized 24 volunteers to wear short sleeves with far-infrared function or without far-infrared function respectively, and then measured the average oxygen content of the biceps and the skin on the abdominal surface. Their experimental results showed that the average oxygen content of biceps and abdominal skin increased by 5% to 8% when wearing the far-infrared T-shirt. Escamilla-Martínez [15] prepared a kind of socks impregnated with bioceramic materials. When testers wore the socks, the temperature of the feet has effectively decreased by about 1.0 °C during the marathon race. It is beneficial to prevent blisters and improve the performance of athletes.

2.2. Textiles with infrared radiation refrigeration function

It was found that many groups in general materials can absorb infrared radiation from the human body, such as N-H, C-O, etc. However, polyolefins such as polyethylene (PE) only contain aliphatic C-C and C-H bonds. Therefore, polyethylene has a very low absorption rate of infrared radiation which is emitted by the human body and most of the infrared radiation to human body can pass through the fabric made by Polyethylene. Jonathan K. Tong has prepared a cooling fabric made by polyethylene [16], the maximum infrared transmittance of the prepared fabric is 0.644, and the minimum infrared reflectance is 0.2. After that, a novel textile with infrared radiation refrigeration function, composed of zinc oxide particles and polyethylene, was developed by Lili Cai from Stanford University [16]. Compared with cotton fabric, it can reduce the temperature of human body by 5-8 °C. The diagram of the structure and function of the composite film is shown in figure 1.

![Figure 1. Structure and function diagram of composite film with infrared radiation cooling function [17]](image)

2.3. Textiles with infrared radiation heat preservation function

Metal materials (such as Au, Ag, Cu, etc.) could be coated on the surface of the fabrics to enhance their infrared reflectance, so as to improve the thermal performance of the fabric. The polyethylene film covered a layer of silver has been product, whose infrared reflectance reaches more than 90%[18]. In pursuit of better warmth retention property, Yue Xuejie has prepared a kind of membrane[19] which is composed of silver, cellulose and carbon nanotubes. Compared with ordinary cotton fabric, the

| Matrixs          | Inorganic powder | Infrared emissivity of matrixs | Infrared emissivity of textiles |
|------------------|------------------|-------------------------------|---------------------------------|
| Cotton cloth     | ZrO₂             | 0.790                         | 0.910[10]                       |
| Carbon fiber membrane | SiO₂, TiO₂, Tourmaline | 0.825                         | 0.981[11]                       |
| Cotton fabric    | Graphene nanoplate | 0.867                         | 0.911[12]                       |
| Polypropylene    | SiO₂, ZnO        | 0.42                          | 0.85[13]                        |

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composite film can increase the temperature of human body by 5.1 °C. The diagram of the structure and function of this composite fabric is shown in figure 2.

![Figure 2. Structure and function diagram of composite fabric with infrared radiation insulation function [18]](image)

2.4. Textiles with infrared radiation heat regulation function

The textiles with infrared radiation heat regulation function are a kind of Janus material. The infrared emissivity on both sides of them are different. Po-Chun Hsu from American Stanford University has prepared a kind of Janus film [20]. One surface of the composite film has a low infrared emissivity of 0.3, the other surface has a high infrared emissivity of 0.9. Yue Xuejie and Zhang Tao from Jiangsu University also prepared a kind of hybrid membrane with different emissivity on the two surfaces [21]. The structure of the hybrid membrane and the functional diagram of infrared radiation heat regulation is shown in figure 3. In addition, hydrotalcite can be used as a material with high infrared emissivity, because its weighted average emissivity is up to 0.973 in the cooling mode.

![Figure 3. Structure and function diagram of hybrid membrane with infrared radiation heat regulation function [21]](image)

3. Preparation technology of functional textiles with infrared radiation

It can be seen from the above introduction that infrared radiation materials can play a pivotal role in the field of textile and clothing. Further improving the properties of infrared radiation textiles or developing new preparation methods of infrared radiation textiles is necessary. For that, the summary of the preparation methods of functional textiles with infrared radiation have been presented, as in table 2.

In the field of textile, the common methods to combine different kinds of materials are: blending, coating, impregnation, magnetron sputtering, etc. Hu Xili [12] used impregnation method to add graphene powder to cotton fabric and the infrared emissivity of the composite fabric reaches 0.911. This method is easy to operate and textiles have excellent infrared radiation properties. But this method inevitably reduces the permeability, softness and hygroscopicity of textiles. Gao Tingting [24] prepared a kind of composite film which consists of carbon nanotube powder and polyacrylonitrile by electrospinning. The method is also easy to operate and prepared textiles have good moisture absorption, softness and air permeability. However, the excessive amount of inorganic powder can affect the mechanical properties of the fiber, the content of inorganic powder is generally less than 10%. So, the infrared emissivity of textiles made by this method is generally lower than that made by impregnation method. Metallic silver
can be deposited on the surface of manganese dioxide fiber film by magnetron sputtering technology [23] This method can significantly improve the infrared reflectance of the textiles conveniently.

### Table 2. Preparation and function of infrared radiation textiles in published literature

| Active constituent | Preparation method | Function                              |
|-------------------|--------------------|----------------------------------------|
| PE [22]           | PE is dissolved in paraffin oil at 180 °C, and then the mixed solution passes through the extruder. PE solidifies and paraffin oil is removed, generating nanoPE microfibres. | infrared radiation refrigeration |
| Carbon, SiO2, TiO2, Tourmaline [11] | SiO2, TiO2, tourmaline and Polyacrylonitrile were added into DMP solvent and stirred to obtain uniform solution, which will become nanofiber membrane by electrospinning and carbonization | improving microcirculation and speeding blood flow. |
| Graphene [12]     | The graphene was mixed with Waterborne polyurethane aqueous emulsion by stirring and then the cotton fabric coating was modified with GNP/WPU composite using pad-dry-cure process | far-infrared-emitting property |
| Silver [23]       | Silver nanoparticles were deposited on the membrane by magnetron sputtering | infrared radiation heat preservation |
| Cu nanowires [21] | Cu nanowires was obtained using a one-pot method | infrared radiation heat preservation |

### 4. The application of infrared radiation functional textiles

In recent years, far-infrared textiles with health care function have gradually attracted people's attention, and a large number of products have been put into the market. In the "patent star" patent retrieval system, the results of searching with the keywords of "textile" and "far infrared" are shown in figure 4. From 2015 to 2019, the number of patents applied for far-infrared textiles in China is gradually increasing, among which the number of applications in 2018 is the largest, which is 302. The number of related patents applied for by foreign countries has decreased dramatically since 2016, and the number of patents applied for in 2019 is only 3, but the number of foreign patents which were applied for in 2016 reached 349. In these patents, most of the textiles with far-infrared function are obtained by adding various inorganic powders into the polymer [25]. Furthermore, some textile technologies that can product the textiles made of polyethylene are very mature and this kind of textiles have effective refrigeration function. Cui Yi research group of Stanford University has mastered a technology that is about the large-scale extrusion of nanoporous polyethylene microfibres for industrial fabric production [22] and the fibres have several colors which are harmless to human body and not easy to fade [26]. In addition, fabrics which is compounded with metal film can tremendously reflect the heat radiated from the human body and effectively enhance the thermal insulation performance of the clothes [27]. The clothes made of these fabrics can not only keep warm, but also have a gorgeous appearance.
5. Conclusions
With the improvement of people's living standards, far-infrared textiles with health care function will be more and more popular. However, the mechanism of the health care function of the human body by infrared radiation is still not clearly understood. Furthermore, the quality of infrared radiation textiles on the market is uneven. The evaluation system of far-infrared textiles needs to become more accurate and objective. In addition, energy conservation is one of the topical issues in daily life. The textiles with infrared radiation refrigeration, infrared radiation heat preservation and infrared radiation heat regulation not only improve thermal comfort of the human body but also cut down a lot of energy consumption. At present, the clothes with radiative cooling or heating function are in short supply in the market. In order to improve this status, researchers can develop more infrared radiation functional textiles. Meanwhile, the transformation of research results into mass-produced goods also requires the efforts of many entrepreneurs.

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