RESEARCH PROGRESS OF WEARABLE ELECTRIC HEATING ELEMENTS

by

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Original scientific paper
https://doi.org/10.2298/TSCI200601117G

The research progress of electric heating elements is summarized in terms of heating element type and thermal performance evaluation. Their shortcomings are summarized, and the development trend is pointed out to provide help and direction guidance for the research of electric heating element.

Key words: *weaving method, performance evaluation, electric heating element*

Introduction

The traditional way of keeping warm is to control the convection, radiation and conduction of heat to prevent heat loss, such textiles are generally large and heavy, making the wearers inconvenient to move freely, especially, in an extremely cold environment. There are many ways of active heat generation, such as phase change materials [1], electric heating elements [2], hygroscopic heating fibers [3], solar heating [4], among which electric heating products are widely used. A heating element is the core of electric heating wearable textiles, which can generate heat actively by connecting the power supply to produce energy to keep warm. Therefore, it is very important to research and develop the electric heating element.

Classification of electric heating elements

Carbon fiber heating element

Carbon fiber heating elements can be divided into two types: linear element and surface element. Due to its high tensile strength and excellent durability, the carbon fiber is coated with insulating protective layer on its surface to make hair wire.

According to the practical needs, different shapes are designed for a linear heater. The surface heater is 2-D, which can be electrically heated by embedding carbon fibers into conductive coating, carbon fiber paper, felt, film [5], sheet and fabric. However, compared with the linear heater, the surface heater is not suitable for the 3-D cutting adaptability for making a clothing.

Graphene heating element

Graphene heating element can be roughly divided into three categories: graphene fiber [6], graphene coating [7], and graphene film [8]. It has excellent performance in heat con-

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duction, conductivity, strength and flexibility, and can be used to prepare flexible electro-thermal fabrics.

Metal characteristic fiber heating element

Metal characteristic fiber mainly includes pure metal fiber and metal coated fiber. The former has excellent mechanical properties, high strength and modulus, good conductivity, high heat resistance and high chemical stability. At present, the preparation methods include cutting, drawing and melt drawing. The latter is to form metal coating on the surface of some non-metallic matrix fibers by certain methods, so as to achieve the conductive effect. At present, the methods of metal plating include chemical coating, electrolyte solution coating, magnetron sputtering, immersion coating and so on.

Heating element coated with conductive polymer

Conductive polymer has not only the conductivity of metal materials, but also the characteristics of polymer materials. Its preparation process is simple, the conductivity is good and adjustable, the mechanical properties are stable, it is light and low price.

Research progress of heating elements

Park *et al.* [9] studied the distance between carbon fiber heating element and skin surface at low temperature, and explored the relationship between carbon fiber heating element and total thermal resistance of multi-layer clothing system, which provided a certain basis for carbon fiber in wearing. There are two methods for application of carbon fiber to electrically heated textiles, one is to connect the long carbon fiber tow as the heating resistance wire with the power supply and an external protective layer [10], the other is to integrate the carbon fiber into a plane and mix it with other textile fibers to make it into a sheet heating fabric [11]. Yang *et al.* [12] prepared a kind of multi wall carbon nanotube composite films, which had good formability and thermochromic function. The carbon fiber electric heating element has the advantages of fast temperature rise, low energy consumption. However, carbon fiber is brittle, not resistant to bending, easy to break in collusion, and easy to be damaged in the washing process. When it is partially broken, it will make the fiber thin and increase the resistance value; when it is completely broken, the heating piece cannot work [13].

Cui [14] used polyester as warp yarn, glass fiber as weft yarn, and graphene conductive fiber was woven in every certain distance. Its temperature distribution uniformity and heating speed were better than carbon fiber electric heating element. Kim and Lee [15] studied the effect of the shape and area of the coating circuit on the electrical heating properties of the fabric. Through the study of reduced graphene oxide (rSGO or rLGO) wafers [16], it was found that the ultra-thin rLGO microchips provided the best protection effect and electrical performance in the AgNW network. German researchers have developed ultra-thin and compressive graphene coating materials for textiles. Compared with other coating materials on the market, the coating materials can optimize the wearing performance, have certain flexibility. Although the production of graphene has been commercialized and scaled up, the equipment and process have been optimized, and the product quality has been continuously improved, there are defects in the preparation process of the structure. When the film is transferred, the surface is easy to be polluted, resulting in the increase of the resistance value, thus affecting the adaptability in electrical application.

In terms of metal characteristic fibers, some scholars discussed the electric heating performance of the fabric by changing the fabric structure and the content of silver coated yarn, including thermal uniformity and thermal stability. Liu *et al.* [17] improved the weaving method of the conductive silk as shown in the fig. 1, which is easy to be integrated into the fabric or clothing. Some scholars have also studied the heat resistance of stainless steel wire knitted fabric and the performance of knitted structure under different power supply, using infrared temperature measurement technology to measure the heat generated by the fabric without physical contact. The results show that the interlock structure is one of the most suitable structures for knitted heating fabrics [18]. Zhao *et al.* [19] studied the influence of modified resistance wire heating element on the dryer, which has great potential to reduce energy consumption. In addition, there are also scholars who have studied the metal composite yarns to make the electrically heated textiles [20, 21]. In terms of metallic coating, the fabric is decorated by dry impregnation and synthetic polyol Ag-NW, so that it has the function of heating [22].

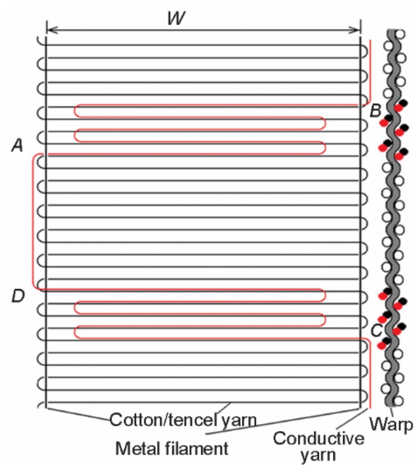

Figure 1. Distribution of conductive yarn and non-conductive weft yarn in heating fabrics

Pure metal fiber has good performance in thermal conductivity, conductivity, high temperature resistance, strength, *etc.*, but it has large friction force and weak cohesive force, which will lead to slippage and separation in the spinning process, resulting in the decrease of yarn structure uniformity, strength, hairiness and wear resistance, which will affect the overall performance of the fabric. Moreover, the elastic recovery rate of metal fiber is low and bending resistance is low because of its small strength, large ratio and lack of elasticity, the wrinkle resistance of pure metal fiber has some defects, *i.e.*, poor softness and no resistance to rubbing. It is easy to break and fall off from the fabric, making the human body itchy. Compared with pure metal fiber, metal coated fiber has some flexibility, but there are also changes in the electrical and thermal properties of metallized fiber in the washing process.

There are many conductive polymers. The amorphous black solid polypyrrole can be prepared by oxidation of pyrrole monomer with catalyst. It does not react with acid and alkali, it can exist stably in air and at high temperature, it has stable conductivity, and it can achieve the effect of electric heating when coated on the fabric surface [23]. Enhanced thermoelectric performances have been achieved in hybrid nanocomposites of TiO_2 incorporated into electrically conductive polyaniline (PANI) through a chemical polymerization process, for next-generation energy sources [24]. Polythiophene doping will change from red to green and its chemical state in the air is not stable. Jiang [25] enhanced thermoelectric properties of polythiophene composites by doping carbon nanotubes. Polyacetylene is difficult to control when it polymerizes has poor solubility in solvent, poor heat resistance, and is unstable in use. In contrast, conducting polymers with nanostructures show higher conductivity, larger specific surface area and better electrochemical activity. This kind of materials combines with other nano materials to form functional nanocomposites to achieve performance improvement.

Performance test of electric heating element

– Thermal stability is the change of resistance with temperature. It is necessary to use infrared thermometer to measure the surface temperature of the fabric and multimeter to measure the resistance. The formula of resistance change rate is:

$$\lambda = \frac{R_0 - Rr}{Rr}100\%$$

where λ is the resistance change rate, R_0 – the initial resistance of the heating element, and Rr – the resistance after heating the heating element.

– The heating rate changes with temperature and time. The temperature can be obtained by measuring the core temperature of the geometric center of the fabric with an infrared thermal imager (with an interval of 10 seconds).
– Power density is an indicator of electric heating effect. The formula is:

$$W = \frac{P}{S}$$

where W is the power density, S [cm^2] – the spraying area of composite fabric, and P is the electric power [26]. The schematic diagram of electric heating performance test is shown in fig. 2.

– The degree of heating will affect the comfort of the fabric [27], and excessive local temperature will cause burns. Heating uniformity refers to the difference of instantaneous temperature of each part of the heating fabric surface, which can be expressed by the temperature distribution coefficient. The smaller the coefficient is, the more uniform the distribution is.

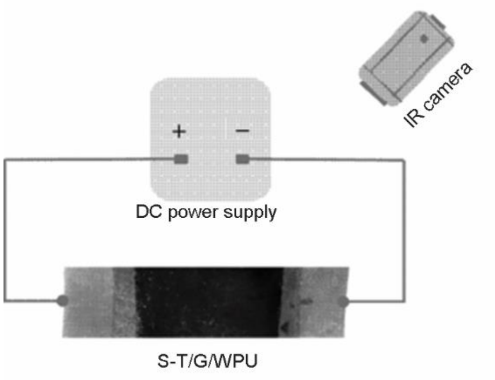

Figure 2. The schematic diagram of electric heating performance test WPU-water-soluble--polyurethane

Conclusion

At present, the research technology of electric heating element is not mature, and it is still faced with poor standardization of evaluation index, no unified standard, single performance test index and incomplete analysis of experimental results by instrument software. In the future, testing instruments with high accuracy and wide adaptability should be developed to lay a foundation for more comprehensive and standard analysis of the performance of electric heating elements or electric heating fabrics. With the continuous in-depth study of electric heating elements, it will also promote the market-oriented, large-scale and commercial development of its related industries.

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Paper submitted: June 1, 2020
Paper revised: July 13, 2020
Paper accepted: July 13, 2020