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Preparation of Highly Efficient Thermal Management Wearable Textiles: Electric Heating Properties and Structural Analysis of Conductive Textiles

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Abstract

To prepare wearable personal thermal management fabric, conductive yarn was synthesised by in-situ polymerisation of polyaniline (PANI) and electroless silver plated nanoparticles (AgNPs) using acrylic (PAN) yarn as substrate. Subsequently, AgNPs/PANI/PAN conductive yarns of different structures are woven. SEM, XRD and FT-IR characterised the structure and properties of AgNPs/PANI/PAN yarns. The resistance and temperature of fabric at different voltages were measured by four probe testers and a thermal infrared imager. The results show that when $AgNO_3$ concentration is 10 g/L, the resistance of AgNPs/PANI/PAN conductive yarn is 0.81 Ω/cm. At the same warp and weft density, the resistance of the satin fabric is 0.272 Ω/sq, and the resistance of the plain fabric is 0.404 Ω/sq. When the voltage is 0.8 V, the equilibrium temperature of the satin fabric reaches 77.6 °C, and that of the plain fabric reaches 63.4 °C. With the increase of applied voltage, the heat loss of satin fabric decreases during the heating process.

Keywords: Acrylic Yarn; Polyaniline; Electroless Silver Plating; Electric Heating Performance

1 Introduction

In general, the temperature of the human body is controlled by the expansion or contraction of blood vessels and the exercise of muscles [1]. However, rapid changes in skin temperature in difficult environments, such as sunlight, wind or cold rain, can lead to discomfort, heatstroke and hypothermia, leading to death. Therefore, it is important to develop portable products that keep the human body warm in cold conditions and protect people from cold and heat by blocking the surrounding heat in hot conditions. In the development of civilisation, clothing has played an important role in controlling heat transfer. Recently, portable string heating products have

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been used in clothing as an important part of individual heat management to raise body temperature. Joule heating products made of conductive textiles have attracted very great interest because of their heating and high-temperature applications. In biomedical or aesthetic applications, tissue heating is becoming a promising material. High heat opens the blood vessels to increase blood circulation and provide nourishment to prevent the wound [2]. In addition, when it comes into contact with human skin, it can significantly accelerate the transdermal delivery of drugs or cosmetic agents [3, 4]. Metal conductive yarns, silver nanoparticles (AgNPs) layer yarn, carbon-based conductive materials, conductive polymer materials and the like are the main electric heating elements currently used for electrically heating fabrics [5, 6]. The temperature of the cotton fabric coated with carbon nanotubes can be raised to 78 °C within 2 min under the voltage of 20 V as the electric heating material [7]; Polypyrrole was polymerized in situ on cotton fabric, and Polyacrylonitrile (PAN) fabric and the sheet resistance of the fabric is 303 Ω/m, and the temperature of the polypyrrole-cotton fabric reaches 28∼83 °C under the voltage of 3∼9 V [8]; Kayacan weaves stainless steel yarn as heating yarn into nylon knitted fabric, the temperature of the four layers of conductive cloth is heated to 12 V for 6 min 60 °C [9]. Liu uses nylon staple yarns and silver-plated conductive yarns to weave a heat-generating fabric with double ribs, which rises to 70 °C in 400 s with an applied voltage of 4 V [10]. PAN fibre has the properties of being mothproof, non-dripping and heat-resistant [11]. May Kahoush et al. immobilized oxidoreductases such as glucose oxidase on the substrate electric fabrics are used for the production of microbial or enzyme fuel cells In the field of material/electrochemical reactors and wastewater treatment, it is both environmentally friendly and safe [12]. Sirui Yao studied a new type of filament coated in Ti_3C_2TxMXene aqueous solution to achieve low resistance (25.6 Ω/cm). The resistance of the coated yarn also showed a linear change in response to tensile deformation, which has the ability for sensing applications [13]. Xiangqin Wang et al. prepared polyaniline (PANI) composite materials using polyvinyl alcohol (PVA) as an emulsifier and oxidative polymerization method. The conductivity of PANI film can reach 1.28 S/cm [14]. In this paper, the conductive AgNPs/PANI/PAN conductive yarn is prepared by in situ polymerization and chemical silver plating, then woven into AgNPs/PANI/PAN conductive fabric to test its electric heating performance. PAN electric heating fabric can provide a reference for researching and developing wearable personal thermal management products.

2 Materials and Methods

2.1 Experimental Materials

Acrylic staple yarn (linear density 28.1 tex, Shaoxing Xineng Textile Technology Co., Ltd.); Anhydrous ethanol (analytically pure), Chengdu Cologne Chemical Co., Ltd.; Silver nitrate ($AgNO_3$, analytical pure), aniline (ANI, analytical pure), Ammonium persulfate (APS, analytical pure), ethylenediamine (analytically pure), sodium hydroxide (NaOH, analytical pure), hydrochloric acid (HCl, 36% concentration), trihydroxyaminomethane (analytically pure), ammonia (analytically pure), glucose (analytically pure), Tianjin Damao Chemical Reagent Factory.

2.2 Preparation of AgNPs/PANI/PAN Conductive Yarn

Immerse PAN yarn in a water bath at 80 °C and 20 g/L sodium hydroxide solution for 30 min for roughening treatment, and then wash it with water and dry it in the air. The coarsened