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Preparation of carbon-based coating for flexible fabric heater by arc ion plating

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ABSTRACT

Electrically heated textiles are being increasingly used in many applications, including clothes, furnishings and medical equipment. Unlike conventional electrically heated textiles, carbon-based coatings such as diamond-like carbons (DLCs) exhibit high chemical stability and effective far-infrared emission, with adjustable electrical resistance. In this study, an arc ion plating (AIP) technique, which can be used for deposition at low temperature, is used to prepare carbon-based coatings on a glass fiber fabric, for use in a flexible fabric heater with a low processing cost and far-infrared emission capability. The C_2H_2 flow rate and deposition time during deposition are adjusted to study the microstructure of the deposited glass fiber fabric and reveal how they affect the electrical properties and far-infrared emissivity. Experimental results show that the I_D/I_G ratio of the obtained carbon-based coatings, as affected by C_2H_2 flow rate and deposition time can greatly influence the properties of the film. Ultimately, the lowest electrical resistance of 6.8 Ω and a far-infrared emissivity of 0.83 with the highest heating rate are obtained. These values are close to those of commercially available carbon fiber fabric. Such an AIP carbon-based coating on flexible fabric heater has great potential for use electrically heated products.

1. Introduction

The demand for light, electrically heated textiles for protection against cold weather has increased rapidly in recent years. Electrically heated textiles are being used in many applications, including clothes, furnishings, car seats, and medical equipment; they have also been used as interior construction materials. Two major heating elements for electrically heated textiles – the conventional metal wire [1,2] and carbon fiber [3] – are currently commercially available. The former suffers non-uniform heating, easily corroded by washing, is uncomfortable for the user and has no far-infrared emission capability, while the carbon fabric performs area heating; is flexible, and emits in the far-infrared. However, the carbonization process for preparing carbon fiber is expensive, energy-consuming and emits environmental unfriendly VOCs [4].

Carbon-based coatings, such as diamond-like carbons (DLCs), known to be amorphous and to mix "diamond" sp^3 with "graphitic" sp^2 bonding, are composed of carbon, hydrocarbon or a small amount of metal [5]. The ratio of sp^3 to sp^2 can be controlled to present a wide range of properties [6]. Their properties can therefore be tuned by the use of different preparation routes and process parameters. They are generally characterized by low friction, high wear resistance, high chemical stability and far-infrared emission [7]. They can therefore be used in many fields [8–10]. Many methods for preparing films have been used to produce DLCs. They include plasma-enhanced chemical vapor deposition (PECVD) [11], ion beam deposition (IBD) [12], magnetron sputtering [13], pulsed laser deposition (PLD) [14] and arc ion plating (AIP) [15,16], each of which has a particular application. AIP has attracted great attention because of its low equipment cost and effectiveness in low-temperature deposition [17].

The AIP technique involves a metal cathode over whose surface highly ionized arcs are ignited to emit metal ions [16]. The inlet reactive gas species are strongly activated in the arc spots and partly compounded with metal ions and partly self-composed to condense over the substrate surface in the form of a solid film. Therefore, dense and strongly adherent coatings can be produced by AIP without additional substrate heating. Notably, AIP coatings may exhibit large variations in film composition and crystallographic features. Carbide film is obtained at a low hydrocarbon gas admittance, while hydrogenated DLCs, or so-called "ta-C", are obtained at higher hydrocarbon gas admittance. Moreover, the concentration of metal in the film can vary, leading to a wide range of electrical properties and mechanical properties. In this regard, "carbon-based coatings" is a more generic term than "DLCs" and are best formed by AIP preparation for use in novel electrically heating textiles without the disadvantages of conventional electrically heated textiles. Therefore, in this study, the AIP technique is used to prepare carbon-based coatings on glass fiber fabrics. The C_2H_2 flow rate and deposition time during deposition are adjusted to investigate the microstructure of the obtained coatings and determine how these factors affect the electrical properties and far-infrared emissivity. A flexible fabric heater with low processing cost and far-infrared emission is expected.

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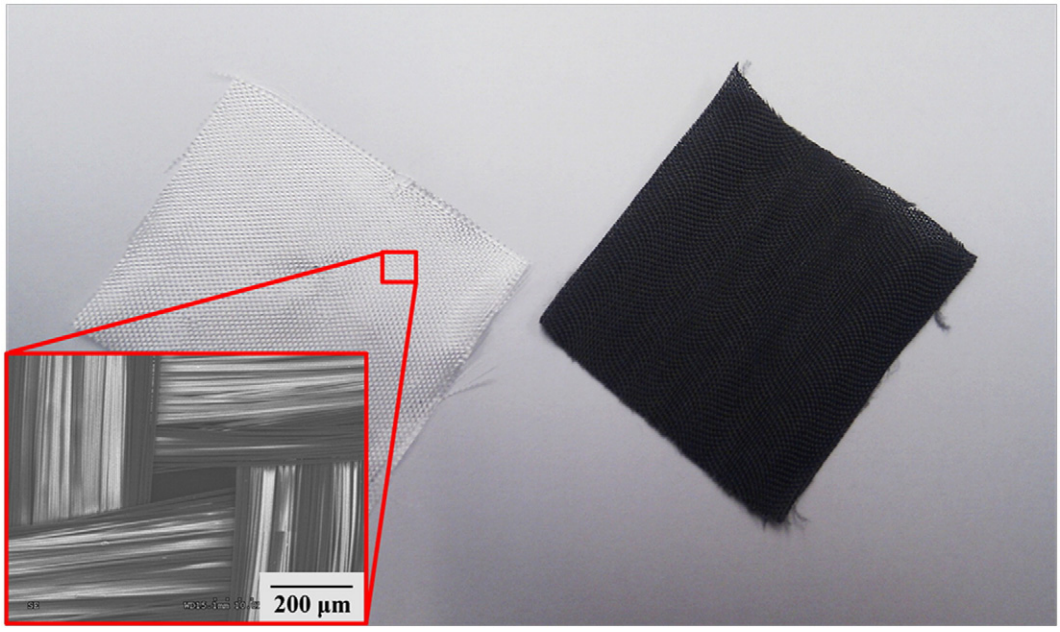

Fig. 1. Raw glass fiber fabric and coated glass fiber fabric.

2. Experimental

Taking advantage of its thermal stability, high strength, flexibility and chemical stability [18,19], glass fiber fabric (with a single filament diameter of 5 μm, a density of 10×8 count/cm^2 and a weight of 47 g/m^2) was used as the substrate in this study as shown in Fig. 1. The size of each specimen was 80 mm×80 mm×1 mm. Carbon-based coatings were prepared using an arc ion plating system, as depicted schematically in Fig. 2. The metal chromium was chosen as a cathode electrode material, shown in the figure, and served as an electrode for generating arc spots during deposition. Utilizing chromium as the cathode material provides benefits in the formation of a conductive interlayer, which also acts to buffer the large thermal expansion coefficient difference (and therefore a huge internal film stress) between the DLC coating and the glass fiber fabric substrate [20–22]. Furthermore, when a chromium cathode is used, the chromium element is incorporated into the deposited film, forming a solid solution of atoms, while some is compounded with carbon as carbide, providing the benefits of lower internal stresses (and therefore improved film adhesion) and high thermal stability (and therefore better resistance against elevated temperatures) of the obtained coatings, as reported elsewhere [23]. The vacuum chamber was initially evacuated to a base pressure of 6×10^{-3} Pa. The coating process comprised three stages, which were glow discharge ion-bombardment for pre-cleaning, interlayer deposition (for improved film adhesion) and the formation of a carbon-based coating. Prior to coating, argon glow discharge bombardment was carried out to remove surface contamination, using the standard operating procedure for arc ion plating. Table 1 summarizes the process parameters for each stage. The C_2H_2 flow rate and deposition time were the two coating variables of interest. The rotation speed of the substrate fixture was set to 6 rpm to ensure that both sides of the glass fiber fabrics were coated to an equal thickness during the deposition. After coating, the coated glass fiber fabric appeared dark gray in Fig. 1.

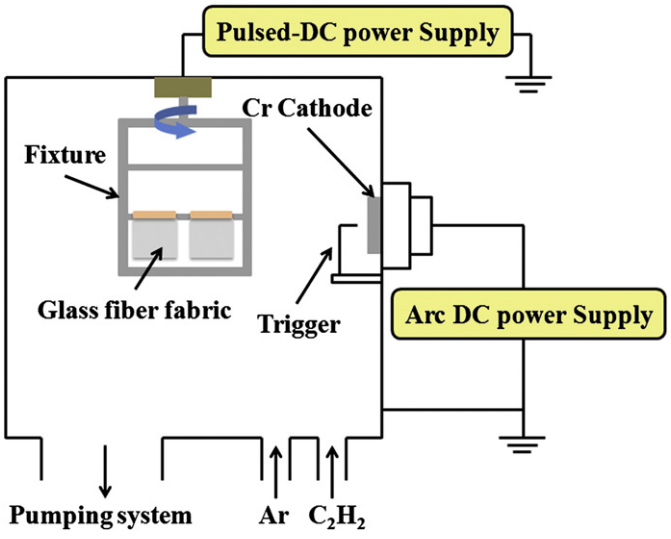

Fig. 2. Arc ion plating system used for carbon-based coating.

Table 1
Process parameters for each state of carbon-based coating process.

Coating parameters			Value
Cathode material			99.5 % Cr
Cathode voltage (V)			20
Cathode current (A)			110
Background pressure (Pa)			6 × 10^{-3}
Glow discharge ion bombardment	Ar flow rate (sccm)		100
	Working pressure (Pa)		1
	Treatment time (min)		5
	Substrate bias (–V)		200
Interlayer coating	Cr	Ar flow rate (sccm)	50
		Working pressure (Pa)	0.5
		Deposition time (min)	5
		Substrate bias (–V)	100
Carbon–based coating	C_2H_2 flow rate	C_2H_2 flow rate (sccm)	50, 100, 150, 200
		Working pressure (Pa)	0.04, 0.10, 0.20, 0.26
		Deposition time (min)	20
		Substrate bias (–V)	100
	Deposition time	C_2H_2 flow rate (sccm)	50
		Working pressure (Pa)	0.04
		Deposition time (min)	20, 30, 40, 60
		Substrate bias (–V)	100