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Study on Ohmic Heating Behavior of Fly Ash Filled Carbon Woven/Epoxy Resin Composite ⋆

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Abstract

The Ohmic heating behavior and electrical property of the carbon fabric/green epoxy composite laminates filled with various concentrations of unmilled fly ash and milled fly ash were investigated in present work. We used an infrared camera to record the change in surface temperature of composites over a period of time by varying the voltage from 0 to 10 V. The results show that the composite containing low concentration of fly ash exhibited the optimum Ohmic heating behavior under different applied voltages. The maximum temperatures of epoxy/carbon composites were adjustable by controlling the concentrations of fly ash fillers as well as the applied voltage. When a certain voltage was applied to the composite, the surface temperature of composite raised to the maximum within 20 s and became stable, then cool down to room temperature in 120 s. In addition, the milled fly ash filled epoxy/carbon composites were found to reveal improvement in electrical heating performance and structural stability over the unmilled fly ash filled composites.

Keywords: Ohmic Heating; Fly Ash; Carbon Woven; Composite Laminates

1 Introduction

Over the past decade, multi-functional applications such as intelligent sensing, intelligent heating, and electrothermal performance have attracted a lot of research interest and conducted numerous research works. There is an overall intriguing interest to seek smart and Ohmic heating materials with superiorities on mechanical, stimuli-responsive and electrical properties [1]. Incorporating an electrically conductive filler such as metal fiber, graphite or other carbon materilas in polymer matrix was typically utilized to achieve this goal. Composite material prepared in this way can

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be used as an Ohmic heating element, which generate heat by the passage of an electric current through a conductor according to the Joule's first law, also known as the Joule–Lenz law [2].

Epoxy/carbon composite is one of the typical examples of such Ohmic heating composites [3, 4]. Epoxy resins, being organic, have high strength, good stiffness, good thermal stability, excellent heat, moisture and chemical resistance. Therefore, they have a wide range of applications including metal coatings, electronics/electrical components, electrical insulators, fiber-reinforced plastic materials, textile finishing, and structural adhesives [5]. For the last few decades, the inclusion of nanoscale carbon-based fillers such as carbon nanofibers [6], carbon nanotubes [7], graphene/graphite nanoplatelets [8], and carbon blacks [9] into insulating epoxy resins, have allowed to obtaining electrically conductive nanocomposites accompanied with unique mechanical and multi-functional properties. Epoxy-based composites reinforced with carbon-based nanofillers have been extensively investigated for the uses in advanced areas such as electromagnetic shielding, electronic components, capacitors, electrodes for rechargeable batteries, sensors and actuators [10].

However, under heating conditions, epoxy resin shows poor performance in structural stability due to its limited mechanical properties, shrinkage ratio and acclimatization [11]. To overcome these problems, during processing in previous studies, various fillers have been introduced into the resins [12, 13]. Most fillers used in the epoxy resins include inorganic [14], organic [15] and ceramic materials [16]. It is accepted that the properties of epoxy composites can be altered by the characteristics of the fillers including shape, size, volume fraction in the resin, as well as the modification of the filler surfaces. Waste fly ash particles is one of the widely used fillers. They are interesting because of their low density, low cost, strong filling ability, and smooth spherical surface.

Fly ash is the residue from combustion of pulverized coal in thermal power stations. It is a mixture of oxides and it is rich in silicon (SiO_2), iron (Fe_2O_3), and aluminum (Al_2O_3). The benefits of fly ash are recognized for a variety of structural products like sport equipment, insulation, automobile bodies, marine craft bodies, fire and heat protection devices [17]. Fly ash based light weight composite materials are also reported to be suitable in automotive, chemical and furniture manufacturing industries due to their improved strength, stiffness and thermal resistance. It has been shown that this type of filler enhances the mechanical properties of composites, especially for highly packed systems [18]. Thermal conductivity can also be improved through the addition of a greater amount of filler into the composites based on epoxy resin [19]. With higher packing and proper arrangement of filler particles, there is a higher possibility that heat transfer paths may be created in the composite [20], resulting in better heat dissipation.

The particle size and surface activity of fly ash play important roles in the interfacial properties of the interface between fly ash particles and matrix. The particle size of the filler is an important factor to govern the size of interface, whereas the surface of the filler determines the strength of the interface [21]. The surface of fly ash is usually modified based on silane or non-silane coupling agents [22]. However, there is limited information on the optimization of the fly ash particle size as well as its surface modification.

In the present study, ball milling process is employed to simultaneously modify, in a single stage, both the size and surface of fly ash particles. Carbon fabric/green epoxy composites containing various concentrations of milled and unmilled fly ash filler were fabricated by hand layup and using the cure technique. Ohmic heating and electrical property of the composite films were characterized using multi-ohmmeter and infrared camera. In addition, Ohmic heating behavior