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Investigation of surface properties and mechanical and tribological behaviors of polyimide based composite coatings

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ABSTRACT

This article focuses on the development and characterization of thermoset polyimide (PI) based composite coatings on aluminum substrates. In order to improve the tribological behavior, PTFE and SiC fillers were added into pure PI to develop composite coatings. A thermal study to validate the condition of the pure PI coating after the elaboration process was performed using DSC analyses and the Tg evolution with the temperature of a pure polyimide sample was investigated.

Then, the influence of the fillers (PTFE and SiC) on surface properties, and mechanical and tribological behaviors of the PI composite coatings is considered. Results showed that, by adding PTFE particles into the pure PI, lower surface energies and lower and stable friction coefficients can be obtained. Besides, the addition of SiC particles improved the mechanical behavior such as hardness and wear resistance of the composite PI–PTFE–SiC coatings. Following the obtained results, correlations between wear rate depending on total surface energy and microhardness were established. Thermogravimetric analysis (TGA) of the PI and PI composite coatings was carried out. The results revealed that the addition of fillers into PI pure matrix improved the thermal stability of the composite coatings.

1. Introduction

Advanced composites exhibit appropriate physical and chemical properties that include light weight characteristics coupled with high stiffness and strength, dimensional and thermal stability, chemical resistance, flexural performance and relatively easy processing. The resin systems used to manufacture advanced composites concern two basic types: thermosetting and thermoplastic polymers. Thermosetting resins such as epoxy, polyurethane, phenolic and amino, and bismaleimide (BMI, polyimide) are widely used in advanced composite manufacturing. As a thermoset polymer, polyimide (PI) possesses outstanding properties such as excellent mechanical and electrical insulating properties, good thermal stability and chemical inertness, high wear resistance and resistance to radiation which make it suitable for a wide range of applications [1]. In spite of the good characteristics of polyimide, studies have been carried out to improve their surface properties and tribological behavior by dispersing different filler materials throughout the polymer matrix. Thus, the PI based composite becomes a promising material with controlled mechanical or tribological properties. Besides, fillers contribute to optimize the operational properties in different applications, such as microelectronics or biomedical devices, components for electrical, aerospace or automotive industries [2–4].

Polyimide is also known as a thermo-stable polymer due to its excellent properties at elevated temperatures (250 and 350 °C). The thermal properties of different synthesized polyimides were already studied by many researchers. For example, high glass transition temperature of polyimide up to 310–315 °C [5,6] or 340 °C [7] and no melting point [5–8] have been observed on different DSC curves. The excellent thermal stability of polyimide from ambient temperature up to 350 °C [9] or 420 °C [6] has been also reported. Moreover, the polyimide has a degradation temperature above 500 °C [5,6].

Polymer based composites reinforced at micro or nanoscale with different fillers such as fibers or solid lubricates have gained development and become promising bulk or coating materials for tribological applications. The mechanical properties of the glass–epoxy composites can be improved with the addition of SiC filler and this composite presents a lower wear rate [10]. The addition of the SiC particles in the polymer matrix as a secondary filler along with graphite into glass–epoxy matrix increases the wear resistance of the composite material [11]. Like many kinds of polymer materials, the PI based composite coatings were also studied. For example, the PI resins filled with solid lubricants such as graphite, MoS_2 and PTFE particles and reinforced with carbon fibers (CF) have shown better friction and anti-wear behavior under water-lubrication rather than dry sliding [1]. The addition of appropriate content of Al_2O_3 nanoparticles into PI improved significantly the tribological behavior [12] of the specimens prepared by compression molding method. Besides, the tribological properties of polyimide based composites demonstrated good friction behavior and improved wear resistance

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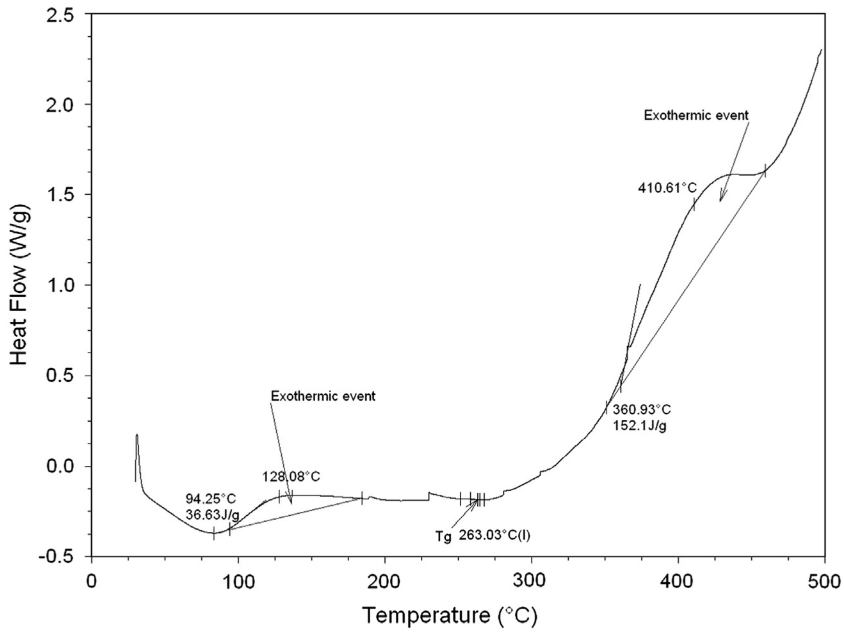

Fig. 1. DSC curve of the PI coatings.

if they are filled with carbon nanotubes (CNT) and Al_2O_3 [12,13]. The graphite additives can control the interfacial sliding conditions, either acting abrasively or adhesively for sintered PI composites [14]. By the addition of graphite as internal lubricant into pure polyimide, lower friction coefficients can be obtained under high loads and high sliding velocities [15]. Besides, increasing SiC whisker content in a SiC–AlN–polyimide matrix composite increased the toughness and decreased the flexural modulus [16].

The use of polyimide based composites as surface protection can improve the tribological behavior and surface properties of different substrate materials. For example, aluminum is widely used in industrial applications for diverse parts and devices, but it possesses poor friction properties. Moreover, polyimide based composite coatings also offer high surface thermal stability when used in tribological applications, even at elevated temperatures. It is already demonstrated that PTFE significantly improved the performances of other polymers such as PEEK [17] and PI [18] because it controls the friction and wear behaviors. Besides, SiC particles as a solid filler also contribute to enhance the mechanical and tribological properties of PI based composites. However, few information about the mechanical and tribological behaviors of polyimide composite coatings filled with PTFE and SiC was reported in the literature. The aim of this study is to investigate the mechanical and tribological behaviors of PI–PTFE and PI—PTFE–SiC composite coatings under dry condition. For this purpose different PTFE weight concentrations as well as a fix amount of SiC particles were incorporated into a fully imidized polyimide resin matrix to fabricate composite coatings. The DSC and TGA analyses were performed on the polyimide solution and pure polyimide and its composite coatings in order to determine the structure after the heat treatment as well as the phenomena which occur during the polymer heating such as glass transition, desolventation and thermal characteristics. Microscopic observations of the coating surface and cross-section were performed in order to reveal the surface morphology. The results of microhardness and tribological tests were correlated with the total surface energy determined by sessile drop method.

2. Coating elaboration and characterization methods

2.1. Composite coating elaboration

PTFE particles with an average diameter of 30 μm were added in 20, 30 and 40 wt.% into a polyimide fully imidized P84 solution (provided by Evonik Industries, Evonik Fibres GmbH, Austria) and well mixed. Polyimide P84 solution is presented in the NEP (N-ethyl-pyrrolidone)

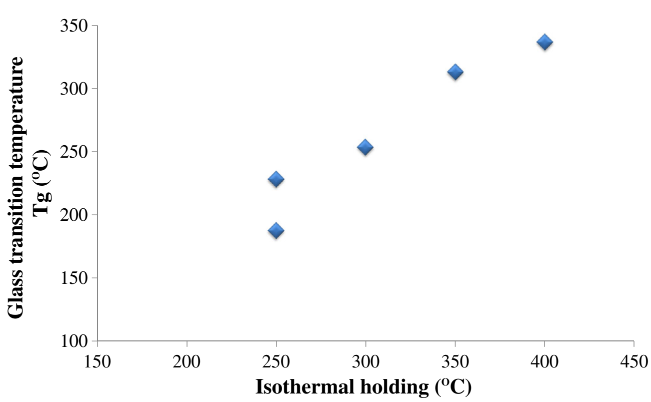

Fig. 2. Evolution of Tg with temperature.

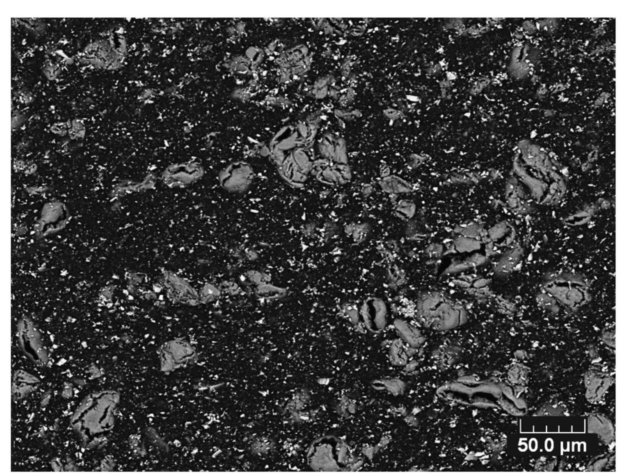

Fig. 3. Surface morphology of PI–20% PTFE–5% SiC composite coating before polishing.