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Erosive wear behaviour of polyphenylenesulphide (PPS) composites

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Abstract

The solid particle erosion behaviour of randomly oriented short glass fibre and mineral particle reinforced polyphenylenesulphide (PPS) composites has been characterised. The erosion rates of these composites have been evaluated at different impingement angles (15–90°) and at three different particle speeds ($v = 20$, 40 and 60 m/s). The particles used for the erosion measurements were silica sand with a diameter of 150–200 μm. Mass flow of sand was 9 g/s, which is impinged under 4.5 bar pressure. The PPS composites showed semi-ductile erosion behaviour, with maximum erosion rate at 60° impingement angle. The impingement angle has a significant influence on erosion rate. The morphology of eroded surfaces was examined by using scanning electron microscopy (SEM). Possible erosion mechanisms were discussed.

Keywords: Particle erosion; Polymer matrix composite; Scanning electron microscopy; Surface morphology

1. Introduction

Polymer composites that were reinforced by unidirectional or short fibres possess usually very high stiffness and strength. Therefore, such composites are frequently used in engineering parts in automobile, aerospace, marine and energetic applications which could be subjected to solid particle erosion [1]. Due to the operational requirements in dusty environments, the erosion characteristics of the polymeric composites may be of high relevance. Erosion tests have been performed under various experimental conditions (erosive particle speed, characteristics, etc.) on different target composites. As known, polymer composite materials exhibit poor erosion resistance as compared to metallic materials [1]. It is also known that the erosive wear of polymer composites is usually higher than that of the un-reinforced polymer matrix [2]. It has been concluded that composite materials present a rather poor erosion resistance [3]. Fibre reinforcement does not enhance the wear performance of polymers in every wear mode. In many cases, it worsens the performance of a neat polymer [4].

The effects of the most important factors influencing the erosion rate of materials are the impact velocity, impact angle of the erodent particles, the size, shape and hardness of eroding particles [5]. In the erosion tests, polymers show ductile nature, and it is known that [6,7] ductile materials have a peak erosion rate around 30° since cutting mechanism is dominant in erosion [6,7]. Glass fibres are a typical brittle material, so that erosion is mainly caused by damage mechanisms as micro-cracking or plastic deformation due to the impact of particle. In a brittle manner, damage is supposed to increase with the increase of kinetic energy loss. According to Hutchings et al. [8], kinetic energy loss is maximum at an impingement angle of 90°, where erosion rates are maximum for brittle materials.

Especially in unidirectional fibre reinforced polymers, there is a strong relation between the particle impingement angle and fibre directions. Under parallel impact, matrix material is easily removed, the particles hit the fibre directly and thus the interface between fibre and matrix becomes

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less dominant. On the other hand, in the case of perpendicular impact, the resistance to the lateral component of bending moment is lower and bundles of fibres get bent and broken more easily.

In random oriented short fibre reinforced polymer composites, there is an interesting morphology, which affects the erosive wear performance of material. Composite material contains a mixture of ductile (polymer) and brittle (short fibre) components. On the other hand, there is a random fibre orientation with respect to the impingement direction (parallel, perpendicular or angular) of the particle which gives a complicate wear morphology.

Polyphenylenesulphide (PPS) materials are used as coating and structural materials in applications, which work under erosive wear conditions. Therefore, study of their behaviour under erosive wear conditions has an important place in machine design. However, a comprehensive and systematic study of erosion of random oriented glass fibre and calcium carbonate filled hybrid PPS composites has not previously been performed.

The objective of the present investigation is to study the solid particle erosion characteristics of random oriented glass fibre and calcium carbonate ($CaCO_3$) mineral particle reinforced hybrid PPS composites under various experimental conditions.

2. Experimental

PPS composites used in this study were kindly supplied from Ticona-GERMANY as injection moulded 80 × 80 mm plaques with a thickness of 2 mm. PPS matrix was reinforced by random oriented short glass fibre (40% w/w) and $CaCO_3$mineral particulate (25% w/w) (total: 65% w/w). The commercial name of the material was 6165A4. Test samples of approximately 40 mm × 40 mm × 2 mm in dimensions were cut using a diamond cutter from injection moulded plaques. Table 1 summarizes the physical properties of the materials [9].

Before the erosive wear tests all specimens were cleaned with acetone, balanced at electronic balance with the accuracy of 0.1 mg. Great care was given to ensure clean surface before and after wear tests. Sand and dust particles were cleaned after erosion test with air blasting and then balanced carefully.

The room temperature erosion test facility used, in the present investigation, the angular silica sand particles with the size of 150–200 μm (Fig. 1) which were driven by a static pressure, P, of 4.5–1.5 bar and were accelerated along a 50 mm long nozzle of 5 mm diameter. The average velocity, (v), of the silica sand at these pressures at the nozzle tip was 60 m/s. Composite samples mounted in the specimen holder. Then mounted specimens were subjected to a particle flow at a given impingement angle between 15° and 90°. Erodent mass flow was measured as 9, 6.25 and 4.25 g/s for 60, 40 and 20 m/s, respectively. Wear was measured by weight loss after each 15 s of erosion.

Table 1
Properties of the short glass fibre/mineral particle reinforced PPS composites

Glass transition temperature (T_g)	110 °C
Melting temperature (T_m)	280 °C
Tensile strength	130 MPa
Tensile modulus	19,000 MPa
Flexural modulus	18,800 MPa
Flexural strength	210 MPa
Compressive strength	230 MPa
Compressive modulus	18,500 MPa
Impact strength Charpy	20 kJ/m^2
Rockwell hardness (Scale M)	100
Density (g/cm^3)	1.95

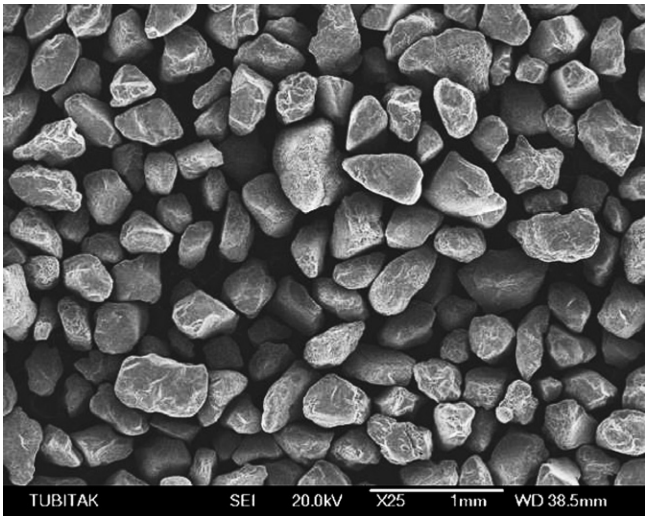

Fig. 1. The angular silica sand particles.

To characterise the morphology of the eroded surfaces and to understand the mechanism of material removal, the eroded samples were observed using a scanning electron microscope (JOEL JSM-6335F field emission scanning electron microscope). The samples were gold sputtered in order to reduce charging of the surface.

3. Results and discussions

Fig. 2 illustrates the weight loss of PPS composite as a function of erosion time at different impingement angles. The curve shows taht a steady state is reached, in which weight loss is proportional to the erosion time that has impacted on the specimen in the form of brittle materials as indicated in Refs. [6,7]. Although lower impingement angles (15° and 30°) tend to result in ductile interaction, no incubation period was observed like in ductile materials. Without an incubation period for all impingement angles (from 15° to 90°) there was a linear proportion for erosion rate and erosion time.

The behaviour of ductile materials like polymers is characterised by maximum erosion rate at low impingement angles (15°–30°). Brittle materials, on the other hand, show maximum erosion under normal impingement angle (90°). Reinforced composites have been shown, however, to exhibit a semi-ductile behaviour with maximum erosion occurring in the angular range 45–60° [10].

Fig. 3 shows the variation of the normalised erosion rates as a function of impingement angles for three different particle speeds. Erosion rates were calculated by dividing the weight loss of specimen by the mass of erodent that impacted. The influence of impingement angle and impact velocity on the erosion rate of short GF and particulate reinforced PPS. The erosion rate is maximum at an impingement angle of 60° (Fig. 3). This is semi-ductile ero-