Short communication

Erosive wear behaviour of carbon fibre/polyetherimide composites under low particle speed

Nejat Sarı, Tamer Sinmazçelik *

Kocaeli University, Department of Mechanical Engineering, Veziroğlu Campus, 41040 Izmit, Turkey

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Abstract

In this study, erosive wear behaviour of unidirectional carbon fibre reinforced polyetherimide (PEI) matrix composites was investigated with regards to the effects of contact speed, contact angles of particles and erosion period under low particle speed. Unidirectional carbon fibre reinforced PEI composites show semi-ductile behaviour under low speed erosive studies. Highest wear rates were investigated at 45° for 1.96 m/s and 50–55° for 2.88 m/s. Higher particle speed was found to be given higher wear rates at higher peak contact angles compared to lower particle speed. Erosive wear rates and the surface roughness have a close relationship with the contact angle of the erodent and speed. Higher particle speed resulted in rougher surface as a result of severe fibre breakage and matrix erosion.

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1. Introduction

If solid particles impinge against a target surface and cause local damage combined with material removal, this kind of wear is generally referred to as erosion. Polymer composite materials have generated wide interest in various engineering fields, particularly in aerospace applications, because they exhibit high specific strength and stiffness as compared to monolithic metal alloys. Polymer composite materials are, therefore, finding increased application under conditions in which they may be subjected to solid particle erosion. Examples of such applications are pipeline carrying sand slurries in petroleum refining, helicopter rotor blades, pump impeller blades, high speed vehicles and aircraft operating in desert environments, water turbines, and aircraft engine blades [1].

However, polymer composite materials exhibit poor erosion resistance as compared to metallic materials [2]. It is also known that the erosive wear of polymer composites is usually higher than that of the unreinforced polymer matrix [3]. Solid particle erosion of polymers and their composites has not been investigated to the extent that it has for metals or ceramics. Many researchers have evaluated the resistance of various types of polymers and their composites to solid particle erosion.

The solid particle erosion behaviour of unidirectional carbon fibre (CF) reinforced polyetheretherketone (PEEK) composites has been characterised by Tewari et al. [4]. Also, the erosion rates of these composites have been evaluated at different impingement angles in different fibre orientations and possible erosion mechanisms are discussed [4]. The effect of fibre length and fibre content on the erosive wear behaviour of glass fibre (GF) reinforced thermoplastic polypropylene (PP) composites was studied by Barkoula [5]. Barkoula also reviewed the previous studies on erosive wear behaviour

* Corresponding author. Tel.: +90 262 335 1148; fax: +90 262 335 2812.
E-mail address: tamersc@yahoo.com (T. Sinmazçelik).
of polymer-based materials. The influence of stacking sequence, existence and position of interleaves on the solid particle erosion in carbon-fibre-reinforced epoxy composites (CFRP) was investigated by Barkoula [6]. The wear behaviour in different types of was modes were studied by Bijwe [7] for polyetherimide (PEI) and its composites containing only short glass fibres (GF) and GF and three solid lubricants. The solid particle erosion behaviour of various polyaryletherketones (PAEKs) and their short fibre reinforced composites have been evaluated at different impingement angles and impact velocities by Harsha et al. [8]. The solid particle erosion behaviour of unidirectional carbon and glass fibre reinforced epoxy composites has been characterised by Tewari et al. The erosive wear of these composites have been evaluated at different impingement angles and at different fibre orientations [9]. The potential of fabric reinforcement in the thermoplastic polymers for enhancing the abrasive wear resistance has not been explored so far. Hence, a series of seven composites of polyetherimide (PEI) reinforced with three types of fabrics, viz. glass (with three different weaves), carbon and aramid (Kevlar 29), was fabricated and abrasive wear performance of these composites along with the neat polymer was evaluated by Bijwe et al. [10]. Although there are limited studies on particle erosion behaviour of PEI composites in high speed particle erosion (over than 40 m/s), there is hardly any study reported in the literature, which is performed under slow speed particle erosion (lower than 3 m/s).

In our present study, we aim to investigate the erosive wear behaviour of unidirectional carbon fibre reinforced PEI matrix composites. PEI has unique engineering properties and this results in very large potential areas in engineering applications. In the literature, there are limited studies which are not sufficient to give adequate information for engineering design for PEI composites. We aimed to investigate the effects of contact speed and contact angles of particles on erosive wear behaviour of PEI composites under low particle speed.

2. Experimental

A schematic illustration of the low speed solid particle erosion rig used in the present study is shown in Fig. 1. The rig consists of a chamber full of sharp, angular silica sand with a particle size between 150 and 200 μm. Samples of 30 x 80 x 2 mm were cut from the composite plaques by a diamond saw for the erosion tests and mounted in the specimen holder. Electric motor drives the system and the speed control unit lets control the travel speed of sample holder in the chamber. Composite specimen was mounted in sample holder. Upper end of the sample was 40-mm beneath the upper sand surface. Composite samples were fixed in a sample holder which could be rotated around the vertical axis. Angle of contact is enabled to be set in the desired angle.

As seen in Fig. 2, composite sample follows the path into the chamber which has an average radius of “r”. Contact angle of the specimen, “α” is 90° in Fig. 2. Contact angle is a very important parameter, which effects the erosive wear behaviour of the samples. The contact angle varies between the 0 and 90° with the 15° increments. The contact angle, “α”, is illustrated in Fig. 3. A standard test procedure was employed for each wear test. The samples were cleaned in acetone, dried and weighed to an accuracy of 0.1 mg using an electronic balance before the wear test. After wear testing, silica particles were removed from the specimen surface by air blasting and weighed again to determine weight loss. All erosion tests were performed at room temperature.
3. Results and discussion

Fig. 4 illustrates the results of wear rates after testing period of 3 h. As seen in Fig. 4, as expected, wear rates of the samples were remarkably higher at higher particle speed. Particles have a higher kinetic energy at higher velocity, which results in greater impingement effect and results in wear. It is investigated that wear rate shows a normal distribution with a maximum point at 45°, especially at lower particle speed (1.96 m/s). The same amount of wear rates was observed around the contact angles of 45°. The wear rates of 0° and 90°, 15° and 75°, and 30° and 60° were approximately the same. At the higher particle speed (2.88 m/s), the maximum contact angle tends to shift to higher degrees (≈50–55°). At higher speed, wear rates were still similar for 0° and 90°, 15° and 75°, but there is a remarkable difference observed in 30° and 60°. 60° gives a higher wear rate compared to 30.

The behaviour of ductile materials is reported 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° [5].

The results of our studies support the previous results of erosive wear studies. Our results indicate that carbon/PEI composites showed semi-ductile behaviour at erosive wear study. Increase in particle speed results in more brittle response of the material, the angle which causes highest wear rate shift to 50–55° from 45° (Fig. 4).

The results of wear rates as a function of wear time are illustrated in Fig. 5 for particle speed of 2.88 m/s. In the first 3 h, the increment in wear rate was nearly linear for each angles. For the small contact angle, it was observed that there was not remarkable increase in wear rate over the 3 h. This behaviour was slightly different for higher contact angles, but linear increments were not observed between the wear rates and testing time, especially over the 3 h.

The erosion behaviour of composites depends strongly on the experimental conditions and the composition of the target material. It is well known that impingement angle is one of the most important parameters in erosion behaviour. When the erosive particles hit the target at low angles, the impact force can be divided into two constituents: one parallel ($F_p$) to the surface of the material and the other vertical ($F_v$). $F_p$ controls the abrasive and $F_v$ is responsible for the impact phenomenon. As the impact angle shifts towards 90, the effects of $F_p$ become marginal. It is obvious that in the case of normal erosion all available energy is dissipated by impact and microcracking, while at oblique angles due to the decisive role of the $F_p$ the damage occurs by microcutting and microploughing [5].
It can be seen from Fig. 6 that, when impacting at low angles, the hard erodent particles can penetrate the surfaces of the samples and cause material removal by microcutting and microploughing. The matrix was randomly grooved and cratered with local material removal under 2.88-m/s particle speed. Because the contact angle is very small (15°), any remarkable matrix loss and any broken fibres are observed in Fig. 6. Between the fibres, which were parallel aligned, the deformation of the matrix material was characterised by ductile flow of the material around the impact site, therefore, a ploughing mechanism was encountered. Matrix removal took place by microcutting. The high temperature, known to occur in solid particle erosion, could soften the matrix. Penetration of silica sand particles in the matrix was not visible in Fig. 6.

Fig. 7 shows micrographs of surfaces eroded at an impingement angle of 45° and at higher particle speed of 2.88 m/s. It is well known that the fibres in composites, subjected to particle erosion, encountered intensive debonding and breakage of the fibres, which were not supported enough by the matrix. The continuous impingement of silica sand on the fibres breaks the fibres because of the formation of cracks perpendicular to their length. The bending of fibres is possible because the surrounding matrix and supporting fibres have been removed (Fig. 7).

The observed erosion damage was characterised by exposure of carbon fibres, fibre–matrix debonding, multiple fibre cracking and material removal. Plastic deformation, melting of matrix, pit formation, fibre removals are also seen on the surface in polymeric composites.

The impingement of the erodent caused roughening of the surface of the material, especially in higher contact angles. Characteristic features of more cutting with chip formation was reflected. Erosion along the fibres and clean removal of the matrix to expose carbon fibres was also seen (Fig. 8). The matrix shows multiple fractures and material removal. The exposed fibres were broken into fragments and thus can be easily removed from the worn surfaces.

4. Conclusion

Experimental results indicate that unidirectional carbon fibre reinforced PEI composites show semi-ductile behaviour under low speed erosive studies. Highest wear rates were investigated at 45° for 1.96 m/s and 50–55° for 2.88 m/s. Higher particle speed was found to be given higher wear rates at higher peak contact angles compared to lower particle speed. Erosive wear rates and the surface roughness have a close relationship with the contact angle of the erodent and speed. Higher
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