



Solid particle erosion behaviour of glass fibre reinforced boric acid filled epoxy resin composites

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ABSTRACT

The tests which involved angular aluminium (Al_2O_3) particles with two different sizes of approximately 200 and 400 μm were conducted at the operating conditions namely different impact velocities of approximately 23, 34 and 53 m/s, two different fibre directions [0° (0/90) and 45° (45/–45)] and three different impingement angles of 30° , 60° and 90° . New composites with addition of Boric Acid filler material at 15% of resin exhibited upper wear than the neat materials without filler material. This means the filler material has decreased the erosion wear resistance. SEM views showing worn out surfaces of the test specimens were scrutinised.

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1. Introduction

Composite materials, often shortened to composites, are engineering or naturally occurring materials made from two or more constituent materials with significantly different physical or chemical properties, which remain separate and distinct at the macroscopic or microscopic scale within the finished structure. As matrix and reinforcement materials are the basic components of composites, the reinforcement materials play an important part in forming any composite material. This is so because when materials of varying specifications are imposed into a matrix, these materials significantly improve one or more operating properties of the newly formed composite [1]. In addition, composites acquire an important place when it comes to operating in a dusty environment where resistance to erosion becomes an important feature. With this aim in mind, composite materials with different specifications were subjected to different erosion experiments. Solid particle erosion wear, which results from solid particles moving at various velocities and impingement angles striking the surface of a material is one of the most encountered types of wear and has recently been a subject of a number of researches [2,3].

Tilly [4] investigated parameters affecting sand erosion of different materials and the selection and development of suitable erosion resistant alloys and coatings. In addition, the researcher found that factors affecting erosion are related to impact conditions, properties of the impacting particles and target material as well.

Miyazaki and Hamao [5] carried out a study to investigate effects of interfacial strength between a matrix material and fibres on the solid particle erosion behaviour of FRPs. The FRPs used were epoxy resins unidirectionally reinforced by carbon fibres. FRPs with treated fibres or untreated fibres were used as test materials to examine the effects of interfacial strength between a matrix material and fibres on the erosion rate. The results of the erosion tests show that FRPs with treated fibres have higher erosion resistance than FRPs with untreated fibres due to higher interfacial strength between matrix material and fibres.

Tsuda et al. [6] scrutinised sand erosion behaviour and wear mechanism of various types of glass fibre reinforced plastics. Erosion behaviour of fibre reinforced plastics changed from ductile to brittle with increase of glass fibre content, and erosion rate was maximum at vertical impact for higher glass fibre content FRP.

Barkoula and Karger-Kocsis [7] investigated the influence of interfacial modification and relative fibre orientation on the solid particle erosion in unidirectional reinforced glass fibre epoxy composites. The erosive wear behaviour was studied in a modified sandblasting apparatus at three impact angles (30° , 60° and 90°). The relative fibre orientation had a negligible effect except the erosion at 30° impact angle.

Rajesh et al. [8] selected a series of polyamides for investigating the effects of chemical structure and hence, mechanical properties on erosive wear behaviour by impinging silica sand particles at various angles and doses. The results indicated that the influence of impact velocity on erosion rate was more dramatic at an oblique impact angle (30°) than at normal impact angle (90°).

Biswas and Satapathy [9] developed a mathematical model for estimating erosion damage caused by solid particle impact on red mud filled glass fibre reinforced epoxy matrix composites and

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also found a correlation derived from the results of Taguchi experimental design. The filler content in the composites, erodent temperature, the impingement angle and velocity are found to have substantial influence in determining the rate of material loss from the composite surface due to erosion.

In a study by Srivastava and Pawar [10], experiments were carried out to study the effects of flyash filler, impingement angle and particle velocity on the solid particle erosion behaviour of E-glass fibre reinforced epoxy composites. The result shows semi-ductile erosion behaviour with maximum erosion rate at 60° impingement angle. The erosion rate displays a strong dependence on impact velocity. They found that erosive wears of GFRP composite with 4 g flyash as filler is the lowest. This filler restricts fibre–matrix debonding. They also concluded that neat glass epoxy without any filler exhibits the highest erosion rate due to weak bonding strength.

Tilly and Sage [11] determined the effects of velocity and dust characteristics on sand erosion. Evaluation of the erosion resistance of materials as diverse as metals, plastics and ceramics shows that there is a very wide range of behaviour that cannot be simply related to a mechanical property such as strength or hardness. Testing of reinforced plastics (type 66 nylon and an epoxy resin) shows that reinforcement may improve or worsen the resistance to erosion, depending on the type of fibres used.

Tewari et al. [12] conducted research on solid particles erosion behaviour of unidirectional carbon and glass fibre reinforced epoxy composites. The erosion wear of these composites was evaluated at different impingement angles and at three different fibre orientations. The unidirectional carbon and glass fibre reinforced epoxy composites showed semi ductile erosion behaviour, with maximum erosion rate at 60° impingement angle. The fibre orientations had significant influence on erosion.

Yang and Nayeb-Hashemi [13] investigated the effects of solid particle erosion on the strength and fatigue properties of E-glass/epoxy composites. In the study, solid particle erosion with SiC particles of 400–500 µm in diameter was simulated with a constant particle velocity of 42.5 m/s at impact angles of 90°, 60° and 30° for 30, 60, 90 and 120 s.

In a study by Harsha and Jha [14] erosion resistances of neat epoxy, unidirectional glass fibre reinforced epoxy and unidirectional carbon fibre reinforced epoxy as well as bidirectional E-glass woven reinforced epoxy composites were investigated. It was found that bidirectional glass fibre reinforced epoxy composites exhibited higher erosion resistance than their unidirectional fibre reinforced counterparts. This is connected to the fact that double directional composites absorb more impact energy.

In this experimental study, neat glass fibre-reinforced epoxy resin composites were selected as the main test specimen and then boric acid was added into this neat structure as a filler material at 15% of resin and thereby new glass fibre reinforced epoxy resin composite material was formed and erosion wear behaviour of this material was investigated under different impact velocities (≈ 23 , 34 and 53 m/s) and using aluminium erodent particle sizes of ≈ 200 and 400 µm and at impingement angles of 30°, 60° and 90° along the fibre directions 0° and 45°. At the end of the tests, graphs of erosion rates and their microscopic views based on the test variations were obtained and related comments were made.

2. Experimental details

2.1. Materials

Glass fibre reinforced composites are obtained as a result of reaction of polyphenol epichloridine under alkaline conditions. Apart from showing relatively high mechanical strengths at room temperature, the materials exhibit good dielectric loss and

Table 1
Properties of test specimens.

Property	GF/EP (neat)	GF/EP (boric acid)
Fibre diameter (µm)	17	17
Fibre areal weight (g/m ²)	200	200
Fibre density (g/cm ³)	2.6	2.6
Density (g/cm ³)	1.683	1.435
Tensile strength (MPa)	533	401
Modulus of elasticity (MPa)	144.3	128.96
Hardness (HB)	87	35
Fibre volume ratio	0.50	0.50

electrical strengths in dry and moisturised environments. The composites have high chemical resistance and can harden at both low and high temperatures. Parallel to the glass fibre reinforced composites, a product of refinery boron, boric acid also occupies an important place in industry where the material is added to the structure to form a new composite. Test specimens made of glass fibre reinforced composite and those made by adding boric acid (≈ 150 µm) to glass fibre reinforced epoxy composites were cut with a diamond saw into plates having thickness of 3 mm and cross section of 30 × 30 mm² capable to be attached to the specimen holder of the test device. They were then located to the specimen holder on the device. Physical and mechanical properties were evaluated as per the ASTM standards given in Table 1.

Arrangement of the fibres in the matrix plays an important role in affecting the strength of the composite. While long fibres arranged parallel to each other in a matrix tend to increase the strength of composites along the fibre direction, arrangement perpendicular to the fibres exhibits rather low strength. Fibres arranged in a bidirectional location provide equal strengths on either direction and homogeneously distributed fibres in the matrix form an isotropic structure.

It is thought that, just as it matters whether the fibres are singly or bidirectionally arranged the directions along which the fibres are located in a structure also have considerable effect on wear. Under the light of this concept, microscopic views of the two specimens having different fibre directions of 0° (0/90) and 45° (45/–45) are given in Fig. 1.

2.2. Erosion testing

The tests were conducted on an erosion wear test apparatus (Fig. 2) specially designed to make sure that the apparatus operates relevant to the ASTM G76-95 standard test method [15], where dry and compressed air is used to accelerate the abrasive particles to strike the test specimen. Pressure changes at the nozzle were adjusted with a pressure regulator and controlled from a manometer. Angular Al₂O₃ abrasive particles with average diameters of 200 and 400 µm were used as eroding agents (Fig. 3). Apart from this, determination of the impact velocity was determined by making use of the double disc method [16]. With this method, the impact velocities of the particles were found to be approximately 23, 34 and 53 m/s. The details of the erosion test parameters for the experiments conducted are given in Table 2. The erosion rate was defined as the weight loss from the specimen surface per unit weight of impinged particles after 10 kg of the particles were blasted over the target specimen.

3. Results and discussion

3.1. Effect of impingement angle (α) and impact velocity (v)

Though it is well known through various studies, that, impact velocity, impingement angle, size of particles, their hardness,

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