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Investigation on solid particle erosion behaviour of polyetherimide and its composites

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Abstract

The present investigation reports about, the solid particle erosion behaviour of randomly oriented short E-glass, carbon fibre and solid lubricants (PTFE, graphite, MoS_2) filled polyetherimide (PEI) composites. The erosion rates (ERs) of these composites have been evaluated at different impingement angles (15–90°) and impact velocities (30–88 m/s). Mechanical properties such as tensile strength (*S*), ultimate elongation to fracture (*e*), hardness (H_V), Izod impact strength (*I*) and shear strength (S_s) seems to be controlling the erosion rate of PEI and its composites. Polyetherimide and its glass, carbon fibre reinforced composites showed semi-ductile erosion behaviour with peak erosion rate at 60° impingement angle. However, glass fibre reinforced PEI composite filled with solid lubricants showed peak erosion rate at 60° impingement angle for impact velocities of 30 and 88 m/s, whereas for intermediate velocities (52 and 60 m/s) peak erosion rate observed at 30° impingement angle. It is observed that 20% (w/w) glass fibre reinforcement helps in improving erosive wear resistance of neat PEI matrix. Erosion efficiency (η) values (0.23–8.2%) indicate micro-ploughing and micro-cutting dominant wear mechanisms. The morphology of eroded surfaces was examined by using scanning electron microscopy (SEM). Possible erosion mechanisms are discussed.

Keywords: Solid particle erosion; Polyetherimide; Erosion resistance; Erosion efficiency; Wear mechanism

1. Introduction

Solid particle erosion manifest itself thinning of components, surface roughening, surface degradation, macroscopic scooping appearance and reduction in functional life of the structure. Hence, solid particle erosion has been considered as a serious problem as it is responsible for many failures in engineering applications. Polymers and their composites find increased applications in the areas where the surfaces are subjected to solid particle erosion. The influence of experimental related parameters (impingement angle, impact velocity, erodent type, size, shape and hardness) and target related properties (strength, ductility, crystallinity, cross link density, reinforcement content and arrangement) on solid particle erosion of polymers and their composites have been reviewed recently by Barkoula and Karger-Kocsis [1]. Many researchers have evaluated the resistance of various types of polymers and their composites to solid particle erosion. Harsha et al. [2] has summarised the work done by the previous investigators on solid particle erosion of polymer composites.

Polyetherimide (PEI) (ULTEM material from GE Plastics) is a high performance amorphous engineering thermoplastic, possessing excellent mechanical properties even at elevated temperature due to its high glass transition temperature (around 217 °C) and also possesses excellent electrical properties [3]. The ULTEM resin in which aromatic imide linkage provides stiffness and high heat resistance while the ether linkage group provides flexibility to the chain and good melt flow characteristics and easy processibility helps for injection moulding. PEI is a transparent and its high ductility is reflected by its elongation to break (60%). It has good chemical resistance and stability to UV and gamma radiations. PEI and its various composites have been evaluated by various investigators for different wear modes [4–15]. Lot of literature is available on study of influence of different fibre reinforcements and solid lubricants on abrasive wear [4–8], sliding wear [4,9–14] and fretting/reciprocating wear [8,15] behaviour of PEI and its composites. It is observed

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that the fibre reinforcement and solid lubricants to PEI matrix at different wear situations may improve or worsen the wear performance of neat PEI. A literature survey showed that detailed investigation on solid particle erosion behaviour of neat PEI and its short fibre reinforced composites has not been reported. Also it is evident that, PEI has immense potential for structural applications and it has not been exploited. Hence, comprehensive and systematic study of erosion behaviour of PEI and its composites is required. This type of study will create large database on erosive wear properties of high performance engineering thermoplastic composites. In view of the above, the objective of the present investigation is to study the influence of different amounts and types of short fibres (glass, carbon) reinforcement on erosion resistance of neat PEI matrix. Another aim of the present study is to study the erosive wear resistance of glass fibre reinforced PEI composite filled with solid lubricants (PTFE, graphite, MoS_2).

2. Experimental details

2.1. Material

The neat PEI matrix and its glass (short E-glass), carbon fibre and solid lubricants (PTFE, graphite, MoS_2) filled composites were supplied by GE Plastics, USA in the form of moulded plaque. The details of PEI and its composites selected for the present study and its designation, fibre/filler content, physical and mechanical properties are listed in Table 1. Micro-hardness (H_V) tests (Shimadzu micro hardness testers, HMV-2) were performed on PEI and its composites at different loads (10–200 g) and a result of 100 g load is reported in Table 1.

2.2. Methodology for evaluation of erosive wear

A schematic diagram of the solid particle erosion test rig used in the present study is shown in Fig. 1. The rig consists of an air compressor, a particle feeder, an air particle mixing and accelerating chamber. Dry compressed air is mixed with the particles, which are fed at a constant rate from a conveyor belt type feeder in to the mixing chamber and then accelerated by passing the mixture through a tungsten carbide (WC) converging nozzle of 4 mm diameter. These accelerated particles impact the specimen, which can be held at various angles with respect to the impacting particles using an adjustable sample holder.

The feed rate of the particles can be controlled by monitoring the distance between the particle feeding hopper and belt drive carrying the particles to mixing chamber. The impact velocity of the particles can be varied by varying the pressure of the compressed air. The velocity of the eroding particles is determined using a rotating disc method [16]. In the present study silica sand ($\rho = 2600\ kg/m^3$) (Knoop hardness = 880) [17] was used as an erodent. Scanning electron micrograph of silica sand is shown in Fig. 2.

Square samples of size 30 mm × 30 mm × 3.2 mm were cut from the plaque for erosion tests. The conditions under which erosion tests were carried out are listed in Table 2. A standard test procedure was employed for each erosion test. The samples were cleaned in acetone, dried and weighed to an accuracy of 1×10^{-5} g using an electronic balance, eroded in the test rig for 5 min and then weighed again to determine weight loss. The ratio of this weight loss to the weight of the eroding particles causing the loss (i.e. testing time × particle feed rate) is then computed

Table 2
Test parameters

Erodent	Silica sand
Erodent size (μm)	150–300
Erodent shape	Irregular, slightly rounded
Impingement angle (α, °)	15, 30, 60, 90
Impact velocity (m/s)	30 ± 4, 52 ± 4, 60 ± 4, 88 ± 4.
Erodent feed rate (g/min)	4.7 ± 0.3
Test temperature	RT
Nozzle to sample distance (mm)	10
Nozzle diameter (mm)	4

Table 1
Material properties (supplier's data)

Property	Test method	Materials and designations					
		Neat PEI A	PEI + 20% GF B	PEI + 30% GF C	PEI + 40% GF D	PEI + 25% CF E	PEI + 25% GF + 15% PTFE + 15% (MoS_2 + graphite) F
Specific gravity	ASTM D792	1.27	1.42	1.51	1.61	1.37	1.7
Tensile strength (MPa)	ASTM D638	105	139	169	186	214	83
Tensile elongation yield (%)	ASTM D638	7.0	–	–	–	–	–
Tensile elongation break (%)	ASTM D638	60	3.0	3.0	2.5	2.0	1.5
Flexural strength (MPa)	ASTM D790	152	207	227	248	289	114
Flexural modulus (MPa)	ASTM D790	3310	6200	8960	11715	15160	8960
Compression strength (MPa)	ASTM D695	151	198	212	219	–	134
Compression modulus (MPa)	ASTM D695	3310	5575	6465	7305	–	4135
Shear strength (MPa)	ASTM D732	103	93	97	103	–	62
Hardness Rockwell (M Scale)	ASTM D785	109	114	114	114	–	85
Micro-hardness (H_V) (at 100 g load)	–	41.9	42.05	46.7	54.64	41.73	29.3
Izod impact unnotched (J/m)	ASTM D4812	1335	481	427	427	69	16
Izod impact notched (J/m)	ASTM D256	32	85	85	112	406	69