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EROSIVE WEAR BEHAVIOR OF SHORT GLASS FIBER REINFORCED POLYETHERIMIDE COMPOSITES

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Abstract- In this work, the erosive wear behavior of Polyetherimide (PEI) and its glass fiber (GF) reinforced composites was studied using silica sand particles at a different impact angles and impact velocities. The erosion rate of these composites has been evaluated at different impingement angles (15–90°) and impact velocities (25–66 m/s). The impingement angle was found to have a significant influence on erosion rate. Composite material showed ductile erosion behavior, with a maximum erosion rate at impingement angle of 30°. The morphology of eroded surfaces was examined by using scanning electron microscope (SEM). Possible erosive wear mechanisms were discussed.
Keywords: Polyertherimide, Glass Fiber, Composites, Erosive wear, Wear Mechanisms.

1. INTRODUCTION

Fiber reinforced polymer (FRP) composites are used in almost every type of advanced engineering structure, with their usage ranging from aircraft, helicopters and spacecraft through to boats, ships and offshore platforms and to automobiles, sports goods, chemical processing equipment and civil infrastructure such as bridges and buildings. The usage of FRP composites continues to grow at an impressive rate as these materials are used more in their existing markets and become established in relatively new markets such as biomedical devices and civil structures.

In many of the above applications, these materials encounter wear and damage processes due to erosion by solid particles. Hence, a study on the erosive wear behavior of such composites has become spot of interest [1].

Polyetherimide (PEI) is a high performance specialty thermoplastic polymer with most of its properties superior to many thermoplastics like Plyetheretherketone (PEEK), Polyamides (PA) and Polypropylene (PP) etc. PEI possesses excellent mechanical properties even at elevated temperature due to its high glass transition temperature (near 217◦C) and also possesses excellent electrical properties [2]. Many scholars studied the erosive behavior of bulk polymers [3-18]. Polymers that have been studied include, polyamide [3, 4], polystyrene [5], polypropylene [6, 7, 9], polyethylene [8, 9], ultra high molecular weight polyethylene [10], polycarbonate and polymethylmethacrylate [11, 12], bismileimide [13], polyetheretherketone [9, 14], rubber and elastomers [15-17], Polyetherimide [18] and polymeric composites [19-32]. Angle of impingement is the most important and widely studied parameter in the case of materials in the literature. Among the available literature on erosive wear behavior of fiber reinforced polymer composites [19–32], a little has been reported on the erosive wear behavior of PEI composites [23, 30]. Hence, it was thought worthwhile to investigate the influence of angle of impingement and velocity on erosion of short glass fiber reinforced PEI composite along with neat PEI. The results of these investigations are discussed in the present paper.

2. EXPERIMENTAL WORK

2.1. Materials

The PEI matrix and its glass (short E-glass) filled composites were supplied by GE Plastics, USA in the form of molded plaques. The details of PEI and its composites selected for the present study, physical and mechanical properties are listed in Table1.

2.2. Erosion testing

In the present study erosion tests are carried out using air jet erosion test rig test rig (as per ASTM-G76). Details of the solid particle erosion test rig used in the present study were given elsewhere [18]. The rig consists of an air compressor, air drying unit, 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 the mixing chamber and then accelerated by passing the mixture through a 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. Monitoring the distance between the particle feeding hopper and the belt drive carrying the particles to mixing chamber can control the feed rate of the erodent. The impact velocity of the erodent can be varied by varying the pressure of the compressed air. The velocity of eroding particles is determined using a rotating double disc method [33].

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Table 1. Physical and mechanical properties of PEI and its composites.

Property	PEI	PEI10	PEI20	PEI30
Fiber weight fraction (wt %)	-	10	20	30
Density (g/cc)	1.27	1.34	1.42	1.51
Tensile strength (MPa)	105	116	139	169
Tensile elongation break (%)	60	6.0	3.0	3.0
Tensile Modulus (MPa)	3450	4685	-	-
Flexural strength (MPa)	152	200	207	227
Flexural modulus (MPa)	3310	4480	6200	8960
Hardness Rockwell (M Scale)	109	114	114	114
Vickers Hardness (HV)	40.0	41.0	42.5	46.7
Izod notched (J/cm)	0.32	0.59	0.85	0.85
Fracture Toughness (MPa $m^{1/2}$)	3.8	3.6	-	-

Table 2: Test parameters

Erodent	Silica sand
Erodent size (μm)	200±50
Erodent shape	Angular
Impingement angle (α, ^{0})	15, 30, 60, 90
Impact velocity (m/s)	25, 37, 50 , 66 (± 4)
Erodent feed rate (g/min)	3.6 ± 0.3
Test temperature	Room Temp.
Nozzle to sample distance (mm)	10
Nozzle diameter (mm)	4

Square samples of size 30 mm x 30 mm x 4 mm were cut from the plaque for erosion tests. The conditions under which the erosion tests were carried out are listed in Table 2. A standard test procedure was employed for each erosion test. The samples were weighed to an accuracy of 0.1 mg using an electronic balance, eroded in test rig for 5 min and then weighed again to determine the weight loss. The ratio of weight loss to the weight of the eroding particles causing loss (i.e. testing time x particle feed rate) is then computed as the dimensionless incremental erosion rate. This procedure repeated till the erosion rate attains a constant steady-state value.

2.3. Microscopic Analysis of Eroded Samples

The characterization of eroded surfaces was done using ZEISS EVO® 50 scanning electron microscope. The samples were silver sputtered in order to reduce charging of the surface.

3. RESULTS AND DISCUSSIONS

3.1. Influence of Impact Angle and Velocity

Steady-state erosion rate (Erosion Rate) of PEI composites as a function of impact angle is plotted in Figure 1. The maximum erosion rate occurs at 30° impact angle and minimum at 90° impact angle for PEI composites. The erosion rates of SGF composites are higher than those of corresponding neat resin. The shape of the curves is similar at different impact velocities (Figure 1). In the literature it has been reported that erosion behavior of SGF composites is strongly influenced by amount of fiber used. Different trends have been reported in relation to erosion behavior and impact angle. Harsha and Thakre [23] reported that PEI and its composites exhibited peak erosion at 60° impact angle indicating semi-ductile behavior at different impact conditions studied. In the present study, all the selected SGF composites exhibited peak erosion around 30° impact angles, indicating ductile erosion behavior. As the amount of resin is higher than fiber in PEI composites, erosion behavior of composites is similar to their resins. However, addition of glass fiber led to higher erosion rates than neat resins.

In order to study the effect of impact velocity, erosion tests were carried out at different impact velocities (25-66 m/s). Figure 2 shows the comparison of erosion rates of PEI composites at different impact velocities for 30 and 90° impact angles. It is obvious that erosion rate increases with increase in impact velocity as the particles kinetic energy increases with velocity. The erosion rate increased about one order of magnitude when the impact velocity increased from 25 to 66 m/s.

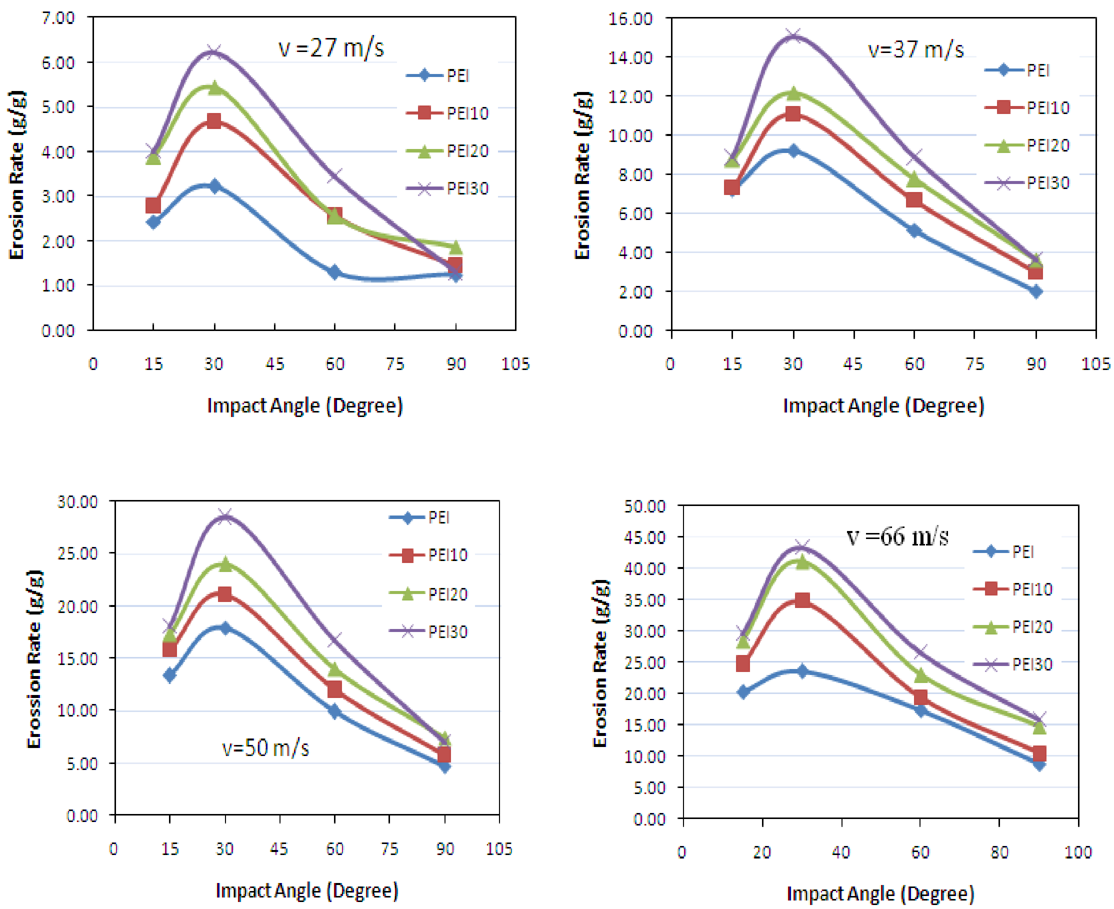


Figure1. Influence of impact angle on erosion rate (x10^{-5}) of PEI and its composites at different impact velocities.

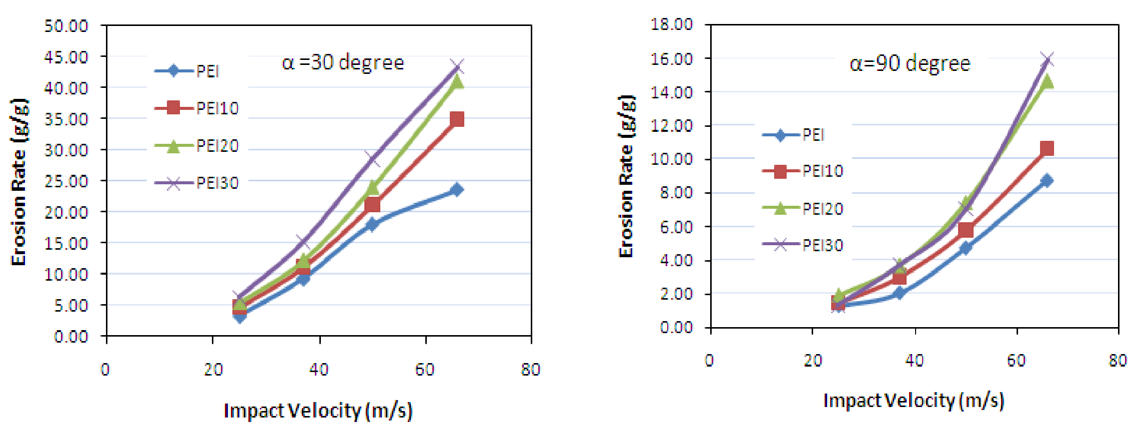


Figure 2. Variation of erosion rate (x10^{-5}) of PEI composites as a function of impact velocity.

3.2. Influence of Glass Fiber Content

Figure 3 depicts the influence of glass fiber content on erosion rate of PEI composites at 30 and 90° impact angles. The erosion rates of PEI composites are higher than that of corresponding neat resins at all impact angles (Figure 1). However, the erosion rate is higher for composites than neat PEI at 30° angle compared to other angles. It can also be seen that the erosion rate increased almost linearly with increase in fiber content at all impact angles. The effect of fiber content is less at impact angle of 90° than other impact angles. The ability of a composite to absorb the energy elastically depends more on its fiber content. It is also reported in the literature that inclusion of brittle fibers in thermoplastic matrices lowers the erosion resistance of composites [20-24].

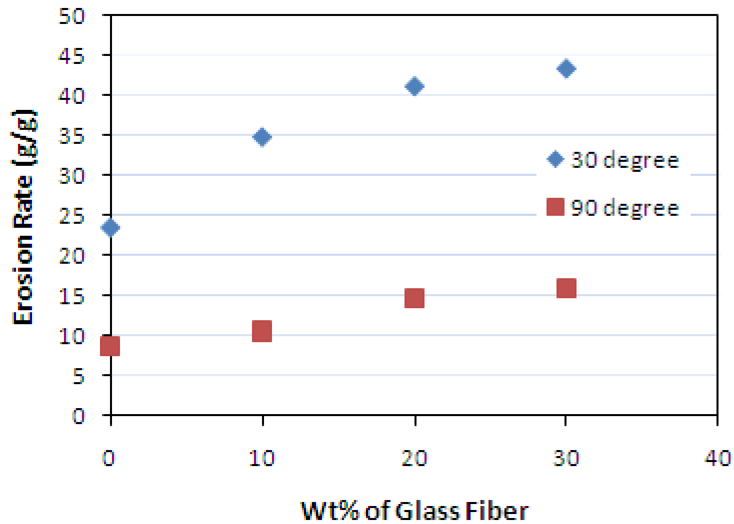
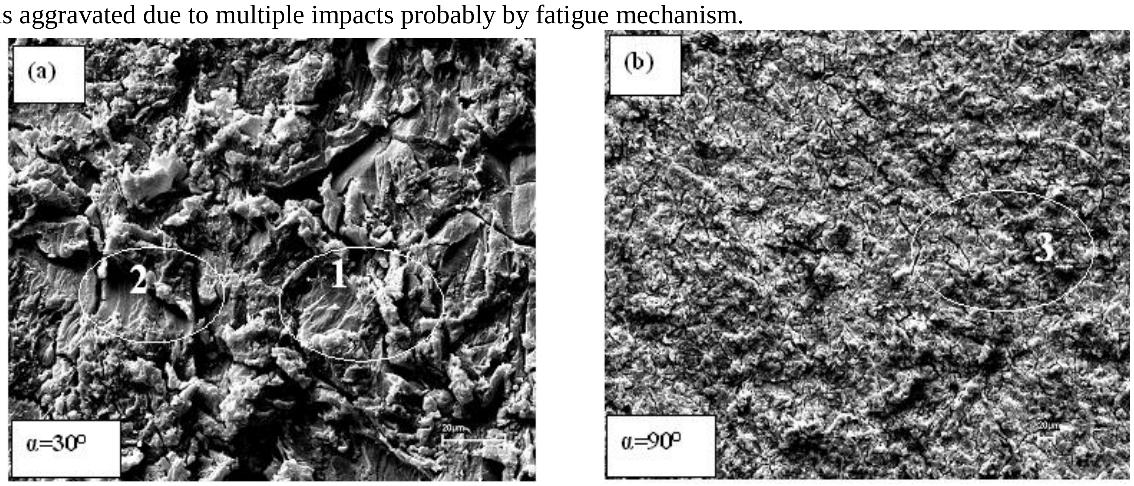


Figure 3. Influence of amount of glass fiber on erosion rate (x10^{-5}) of PEI and its composites.

3.3 Wear Mechanisms

Scanning electron microscopy (SEM) studies have been done to ascertain the wear mechanisms at 30° and 90° impact angles. Micrographs of eroded surfaces of PEI are shown in Figure 4. Typical characteristic features of abrasion marks and small groves (marked as 1) due to erosion are seen at oblique impact angle (Fig.ure 4a). It is also evident from the micrograph that microcutting (marked as 2) is the dominating mechanism of material removal. PEI is an amorphous ductile polymer. However, the failure mode does not reflect any ductility instead a brittle failure in the micrograph. During normal impact, the propagation of cracks along transverse as well as longitudinal directions (marked as 3) can be seen in the micrograph of lower magnification (Figure 4b). At higher magnification the network of these cracks can be clearly seen (Figure 4c). This cracking is aggravated due to multiple impacts probably by fatigue mechanism.



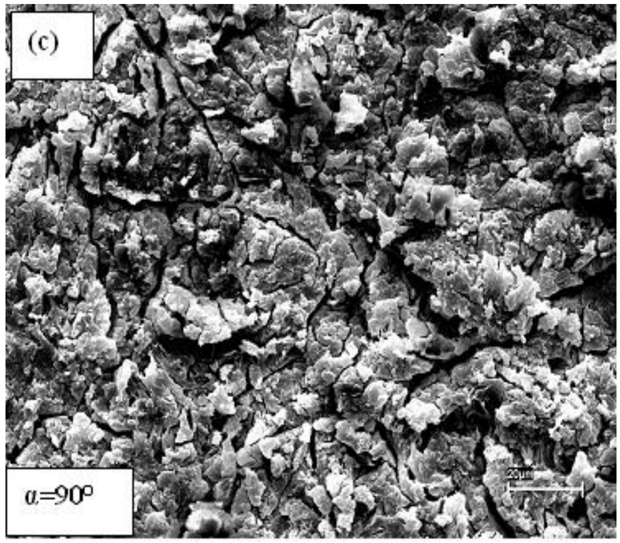


Figure 4. Scanning electron micrographs of neat PEI surfaces eroded at an impact velocity of 66 m/s.

The micrographs of surfaces of PEI composites eroded at impact angle of 30° are shown in Figure 5. Micrographs (a-c) are for PEI+30% GF (PEI30). Typical characteristic features of abrasion marks and small groves due to erosion are seen (Figure 5a and b). It is also evident from the micrograph that microcutting and ploughing are the dominating mechanisms of matrix removal. Upon the removal of matrix the exposed fibers are washed out forming a crater (marked as 6) in the surface (Figure 5c).

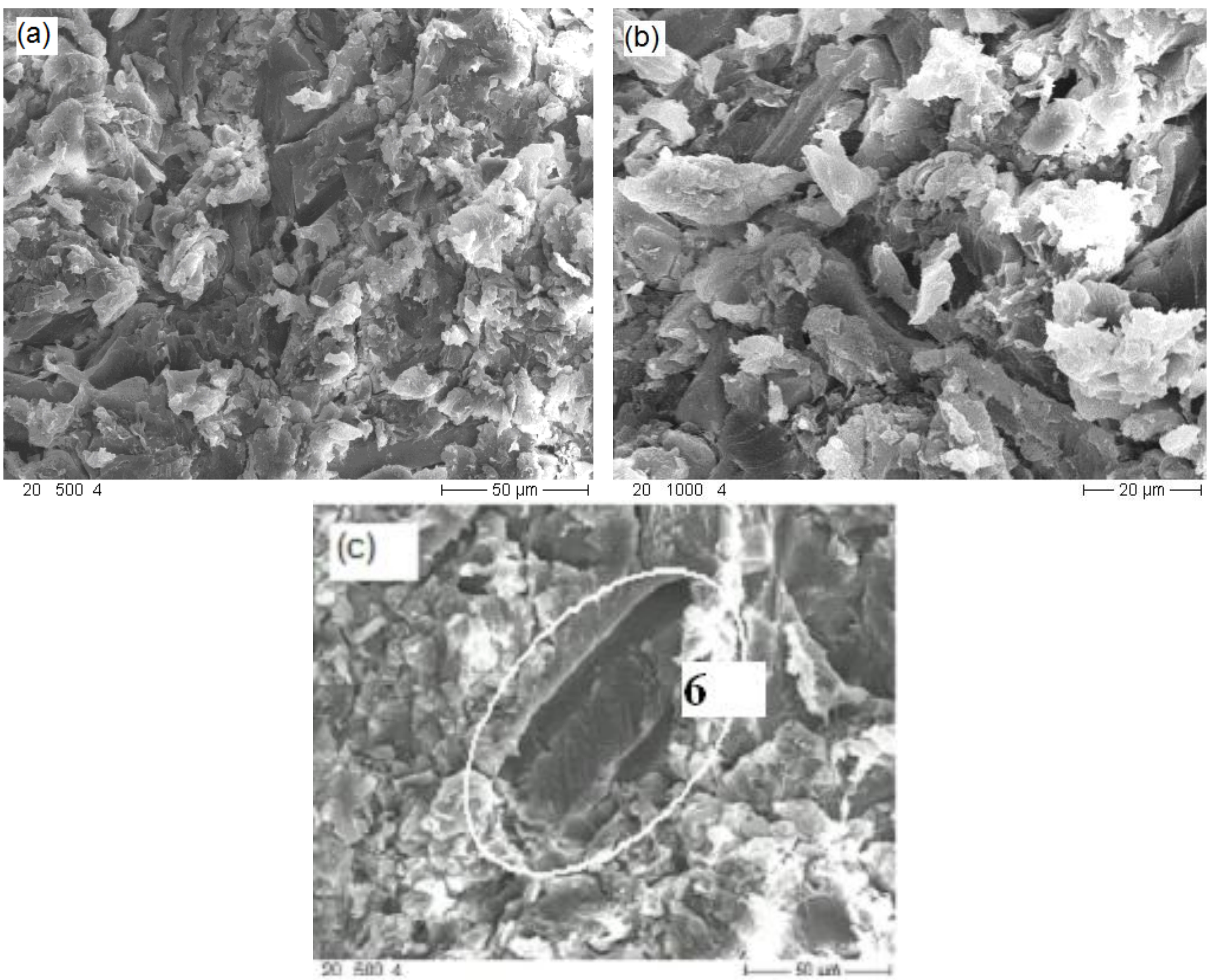


Figure 5. Scanning electron micrographs of PEI30 composite surface eroded at an impact angle of 30° and impact velocity of 66m/s.

The micrographs of surfaces of PEI composites at impact angle of 90° are shown in Figure 6. The micrographs are for PEI+30% GF (PEI30). The network of microcracks and plastic deformation of matrix can be seen in the micrograph of lower magnification (Fig.ure 6a). At higher magnification the network of these cracks (marked as 5) can be clearly seen (Figure 6b). This cracking is aggravated due to multiple impacts probably by fatigue mechanism. The exposed fibers are seemed to be washed out from the surface. At normal impact, the amount of erosion is less due to more amount of plastic deformation compared to other impact angles.

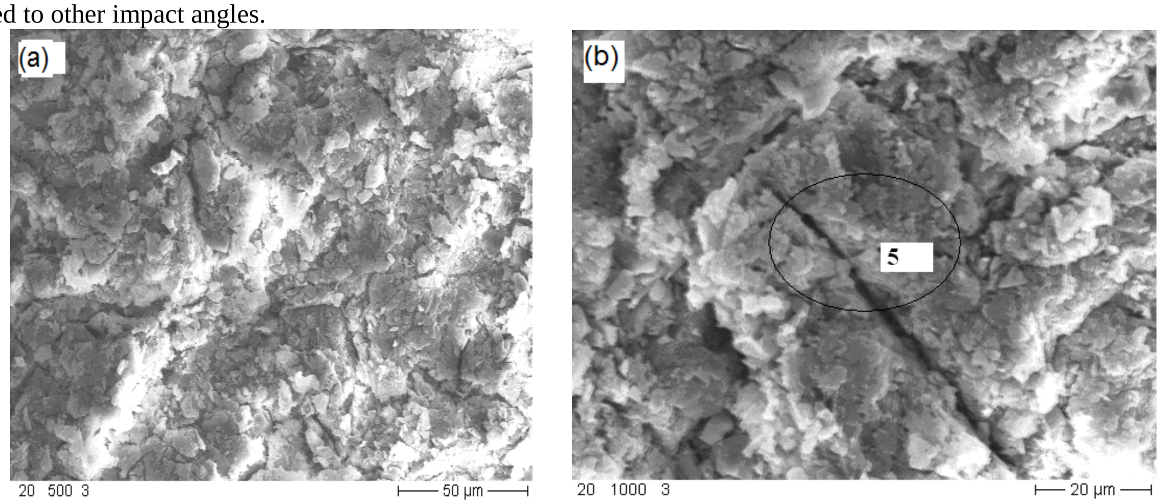


Figure 6. Scanning electron micrographs of PEI30 surface eroded at an impact angle of 90° and impact velocity of 66m/s.

4. CONCLUSIONS

The present study was aimed at investigating the influence of experimental conditions on erosive wear behavior of PEI and its composites. The following conclusions are drawn.

- SGF reinforced composites exhibited maximum erosion rate at 30˚ impact angle indicating ductile erosion behavior. Minimum erosion occurred at 90˚ impact angle. Moreover, erosion rate at 30˚ impact angle is three times higher than that of erosion rate at 90˚ impact angle.
- The erosion rate of the SGF composites increased with increase in fiber content and impact velocity. The maximum erosion rate increased by nearly one order of magnitude when the velocity increased from 25 to 66 m/s.
- The fiber content had a strong influence on the erosion rate of PEI composites. The erosion rate was higher in fiber reinforced composites than neat PEI resin.
- SEM studies revealed that material removal takes place by microcutting, plastic deformation, and micro cracking, exposure of fibers and removal of the fibers.

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