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EROSION BEHAVIOR OF EPOXY COMPOSITES REINFORCED BY GLASS FIBRE AND FILLED BY SYNTHETIC OIL

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ABSTRACT
Erosion of material surface due to solid particles has been a challenge to several fields of engineering. Despite of decades of investigations and research, the exact phenomenon of erosion of surface by the solid particles has not been fully understood. In the present work, the solid particle erosion of epoxy glass fibre composites (Epoxy/GF) is investigated by sand blasting equipment. The impact angles (30°, 60°, and 90°), distance from the sand jet and oil content (2.5, 5, 7.5, 10) filling epoxy matrix are studied. The results show a strong dependency of oil content on the material behaviour form brittle to ductile. The morphology of eroded surface is observed under microscope and damage mechanisms are discussed.

KEYWORDS
Wear, erosion mechanism, epoxy, glass fibre, composites.

INTRODUCTION
Composites are engineering materials made from two or more constituent materials with significantly different physical or chemical properties, which remain clearly separate at the macroscopic scale. As matrix and reinforcement materials are the basic components of composites, the reinforcement materials play an important part in performance of any composite material, [1 - 4]. This is 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.

Polymer composite materials have generated wide interest in most engineering fields, specially in aerospace applications, because they high specific strength and stiffness as compared to metal alloys. Polymer composite materials are therefore finding increased application under conditions in which they may be subjected to solid particle erosion, [3, 5 - 9]. Examples of such applications are pipe line 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. It has been concluded that composite materials shows a rather poor erosion resistance.

A determinate parameter for the design with composites is the fibre content, as it controls the mechanical responses. In order to obtain the favoured material properties for a particular application, it is important to know how the material performance changes with the fibre content under given loading conditions, [4, 10, 11]. The erosive wear behaviour of polymer composite systems as a function of fibre content has been investigated in the past it was accomplished that the inclusion of brittle fibres in both thermosetting and thermoplastic matrices leads to compositions with lower erosion resistance. The influence, of interfacial modification and relative fibre orientation on the solid particle erosion in unidirectional reinforced glass fibre epoxy composites, was studied, [4]. The erosive wear behaviour was studied in modified sand blasting apparatus at three impact angles (30º, 60º and 90º).The relative fibre orientation had a negligible effect except the erosion at30 impact angle.

Parameters affecting sand erosion of different materials and the selection and development of suitable erosion resistant alloys and coatings were investigated, [8]. In addition, the researcher found that factors affecting erosion are related to impact conditions, properties of the impacting particles and target material as well.

A research, on solid particles erosion behaviour of unidirectional carbon and glass fibre reinforced epoxy composites, was conducted, [10]. 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 60º impingement angle. The fibre orientations had significant influence on erosion.

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, [12]. It was found that bidirectional glass fibre reinforced epoxy compo- sites 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 work, fibre glass reinforced epoxy resin composites were selected as the main test specimen and the synthetic oil was added into these composites with different contents. The behaviour of this material was investigated under different impact distances (6, 10, and 16 cm) and using sand erodent particle size of 600 µm at impingement angles of 30º, 60º and 90º along the fibre directions 0º and 90º. Graphs of erosion rate and their microscopic views based on the test variations were obtained and related comments were made.

EXPERIMENTAL

Epoxy reinforced glass fibre specimens are prepared by lay-up method with rectangle geometry dimensions 80 × 80 mm and 3mm thickness. The epoxy is product of JOTUN company with commercial name (jotafloor solvent free primer b20). In this study, synthetic oil (5W40) is added to epoxy mixture of 2.5, 5, 7.5 and 10 wt. % oil content.

The tests were conducted on an erosion wear test apparatus, where dry compressed air is used to accelerate the abrasive particles to strike the test specimen. The sand particles are driven by air pressure at room temperature. The time of the test was 4 min. at approximate steady air pressure.

All the erosion tests were performed in a sand-blasting chamber, Figs. 1 and 2. The distances between the sample holder and the nozzle were 60, 100 and 160 mm corresponding to 9.5, 7.2 and 6.5 m/s particle velocities respectively. The impact angle was adjusted by tilting the sample holder. Three impingement angles were selected 30°, 60° and 90°. The erosion tests were operated at room temperature.

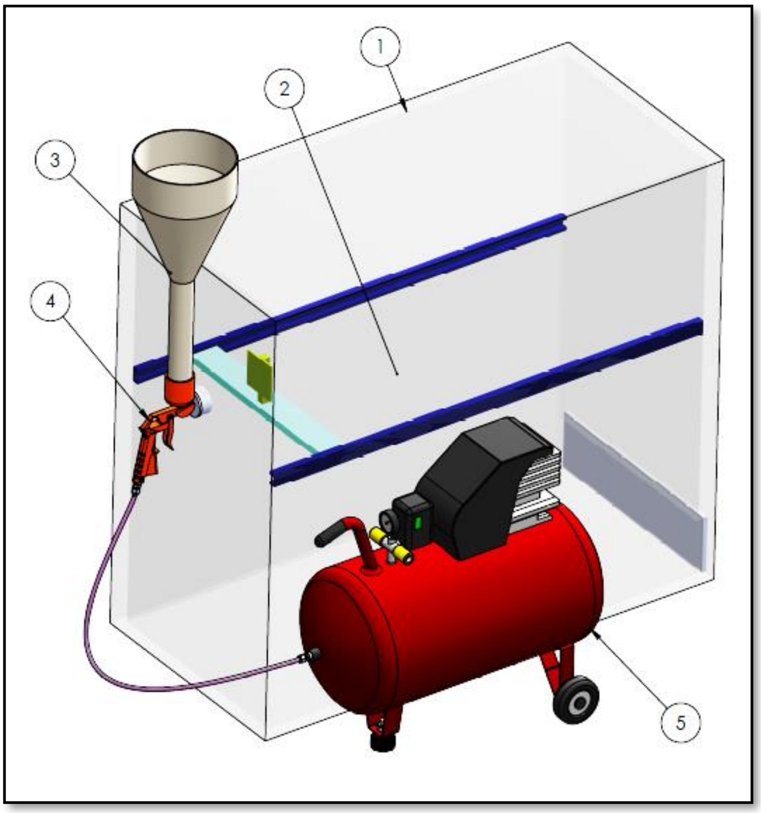


Fig. 1 Sand erosion apparatus. (1) Sand blast chamber, (2) (epoxy/Gf/oil) specimen, (3) Sand abrasive container, (4) abrasive gun and (5) air compressor.

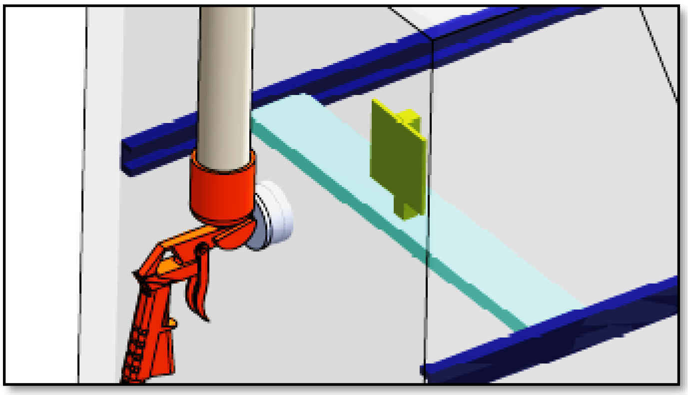


Fig. 2 Sand jet and specimen location.

RESULTS AND DISCUSSION

It is well known that, impact velocity, impingement angle, size of particles, their hardness, shape, type and flow rate plus the properties of target material and environmental parameters, all have important effects on erosive wear. This effect shows the variations depending upon whether the material tested is ductile, semi ductile or brittle. Taking these features into account, the studied factors have generally shown that the maximum erosion rate of ductile materials occurs at impingement angle of 30º, whereas maximum erosion rate of brittle materials occurs at 90º impingement angle. The maximum erosion rate of semi ductile materials was found to occur at impingement angle of 60º.

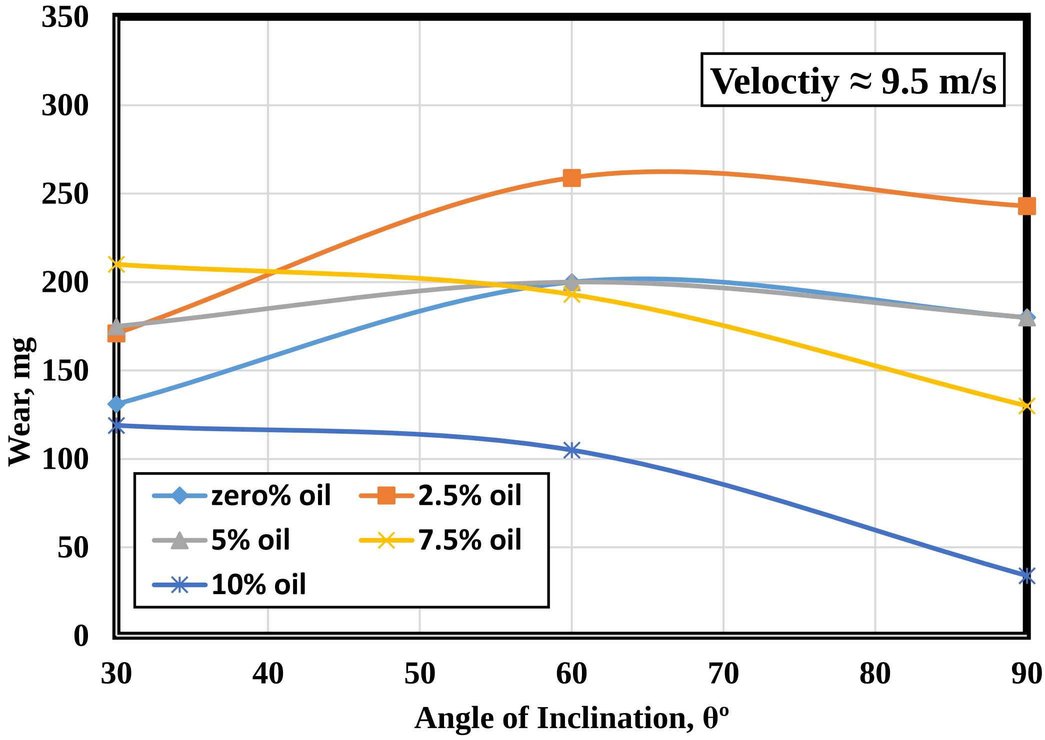


Fig. 3 Relationship between impact angle and weight loss for 60 mm distance far from sand jet.

Figure 3 shows that the relation between inclination angle and wear at calculated sand jet velocity of 9.5 m/s. The maximum erosion happened at 2.5 wt. % oil content and the minimum erosion occurs for composites containing 10 wt. % oil at 90º impact angle. For 7.5 and 10 wt. % oil content, it has also been observed that, parallel to the increase of the impingement angles (60º – 90º), the erosion rates tend to progressively decrease. This condition shows that a similar wear was observed for ductile materials, [4]. It was clear also from Fig. 2 that wear increases at 30º impact angle. This shows behaviour of semi ductile material for zero, 2.5 and 5 wt. % oil content in the tested composites.

The relationship between wear and inculcation angle at 7.2 m/s calculated particle velocity is shown in Fig. 4.It can be noticed that the wear values were decreasing due to change in velocity of the particle comparing to Fig. 3. The minimum wear occurs at 90º at 10 wt. % oil containing. On the other hand, the maximum value presents at 2.5 wt. % oil containing at 60º impact angle. However, the behavior of 2.5 and 5 wt. % oil content, was the trend of semi ductile material according to the angle of 60º maximum wear.The behavior of 7.5 and 10% wt.% oil contents the trends observed can be describe as

ductile material because the maximum erosion wear observed at 30º impact angle of abrasive particle.

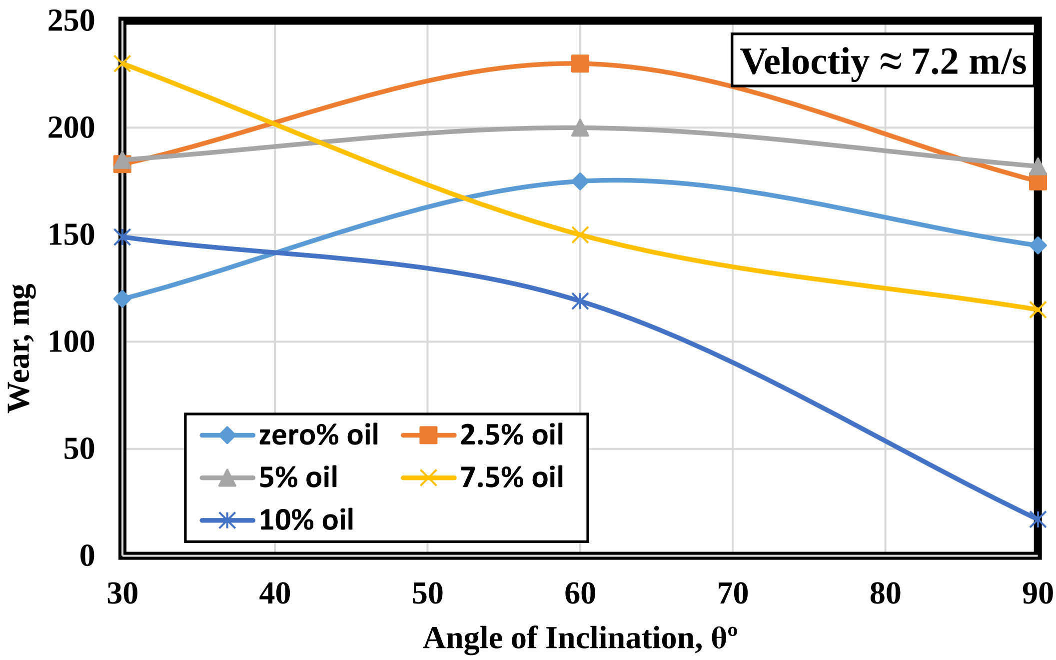


Fig. 4 Relationship between impact angle and weight loss for distance 100 mm far from jet.

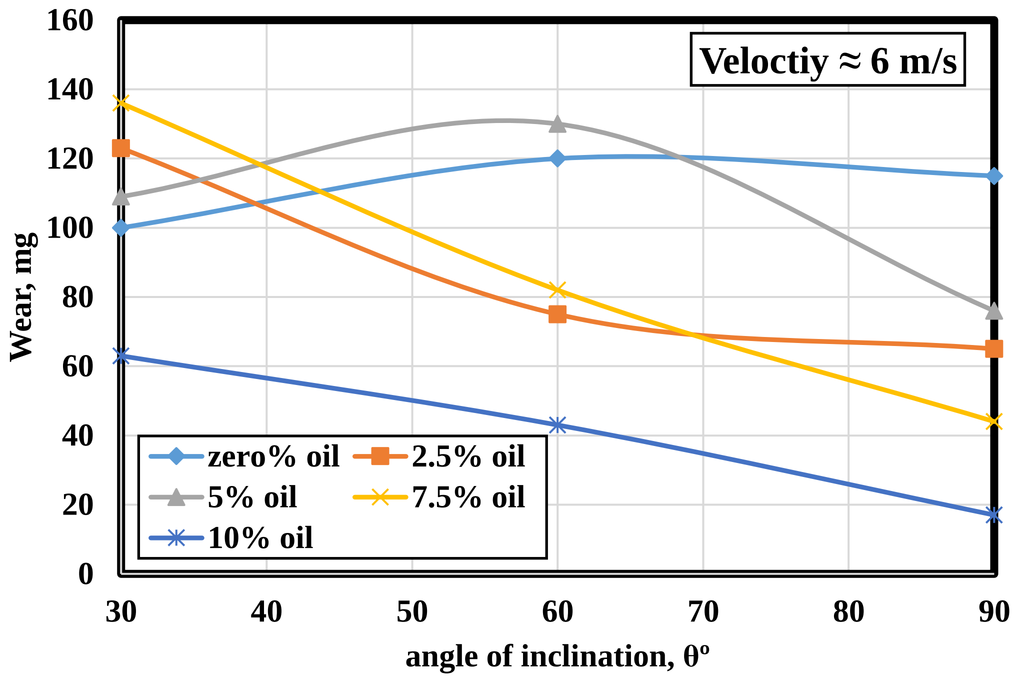
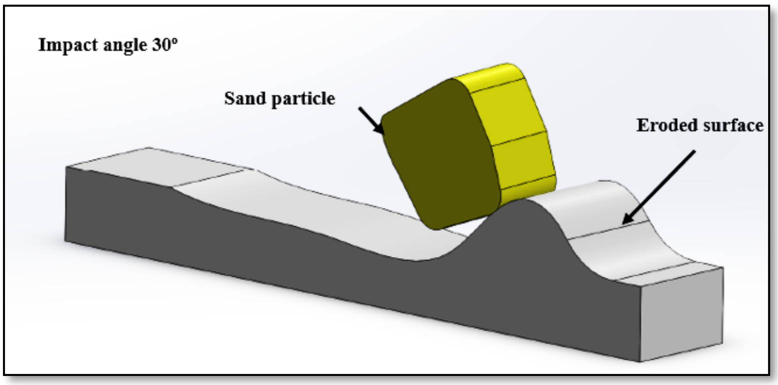
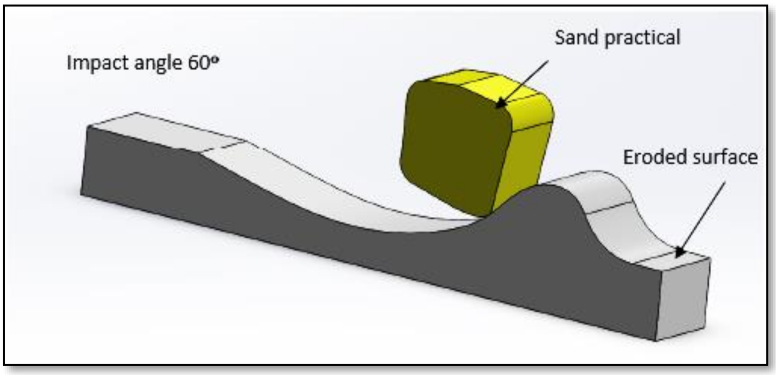


Fig. 5 Relationship between impact angle and weight loss for distance 160 mm far from sand jet.

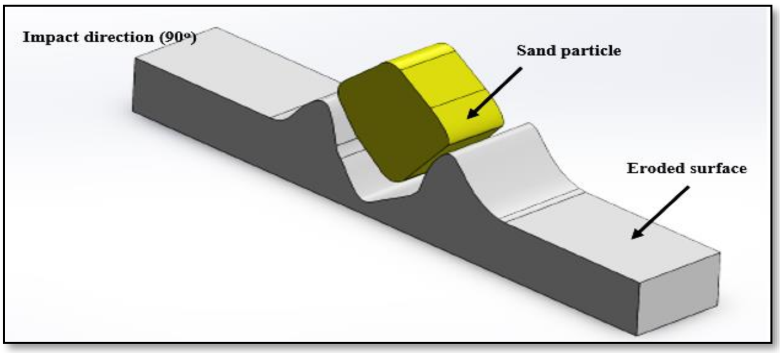
Figure 5 demonstrates the effect of impact angle on wear at approximate calculated velocity of 6 m/s. It is obvious that the minimum erosion takes place at 90º for 10 wt.% oil content. However, the maximum erosion occurred in 7.5 wt. % oil at 30º. The cause is attributed to the oil content which transforms the target material from semi ductile material to ductile one. There was a significant decrease in the values of wear at this impact velocity 6 m/s compared to 9.5 m/s impact velocity. The decrease is close to 51%.



(a)



(b)



(c)

Fig. 6 Wear mechanism of displayed by sand particle, (a) 30º impact angle, (b) 60º impact angle and (c) 90º impact angle.

Wear mechanism of solid particle erosion is shown in Fig. 6. It is seen that 30° inclination angle of sand particle generates a large eroded zone Fig. 6 a, which is the case of ductile material, where the maximum wear erosion occurred at 30° impact angle. Figure 6 b demonstrates the mechanism of impact wear at 60°. Semi ductile material shows maximum wear erosion at this angle. Besides, it can be noticed that when sand particle hits a ductile surface at 90° inclination angle, plastic deformation occurs as shown in Fig. 6 c. The plastic deformation is responsible for minimizing the wear of the target surface.

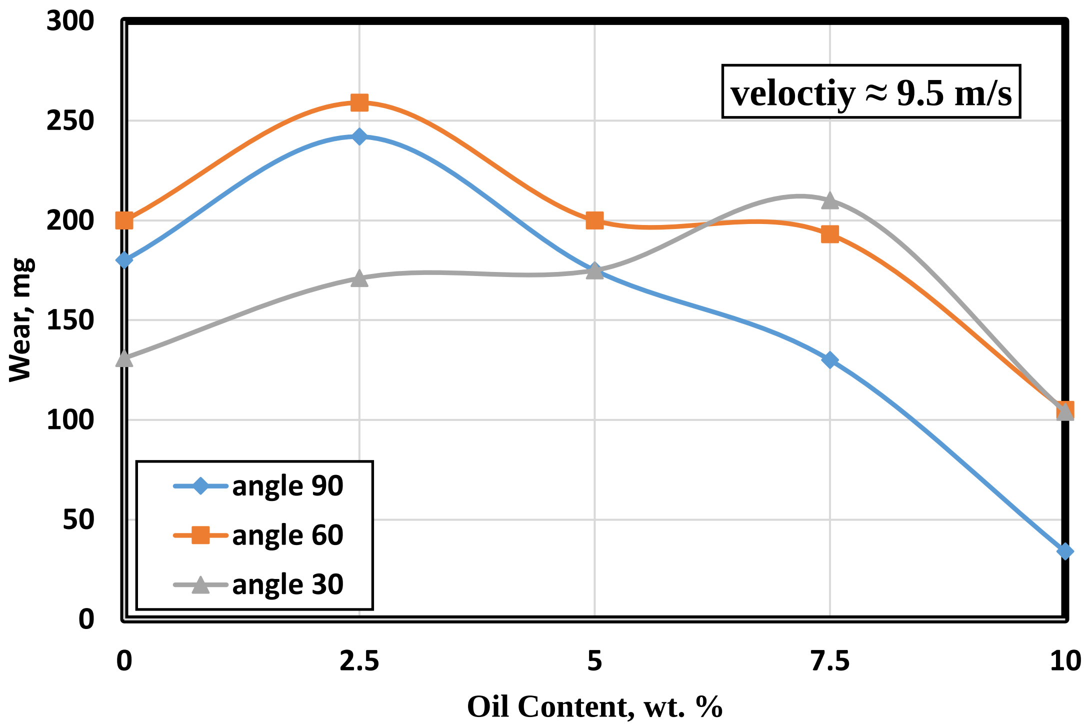


Fig. 7 Relationship between oil content and wear at 9.5 m/s particle velocity.

Figaure.7 indicates the effect of adding oil to (Epoxy/Gf) composites on wear at calculated impact velocity of 9.5 m/s. It is obvious that increasing oil content decreases wear. The maximum wear takes place at 2.5 wt. % oil at all inclination angles. In addition to that, minimum wear occurs at 90° inclination angle. It can be noticed that 5 wt. % oil shows a significant in wear value for 30° angle.

Figure 8 illustrates the effect of adding oil to Epoxy/Gf composites on wear at calculated impact velocity of 7.2 m/s. It is noticed that with increasing oil content wear decreases. The maximum wear takes place at 5 wt. % oil. Besides, 90° inclination angle shows the minimum wear for all percentage of oil content. It can be noticed that 5 wt. % oil content shows a reversal in wear value for impact angle 30°.

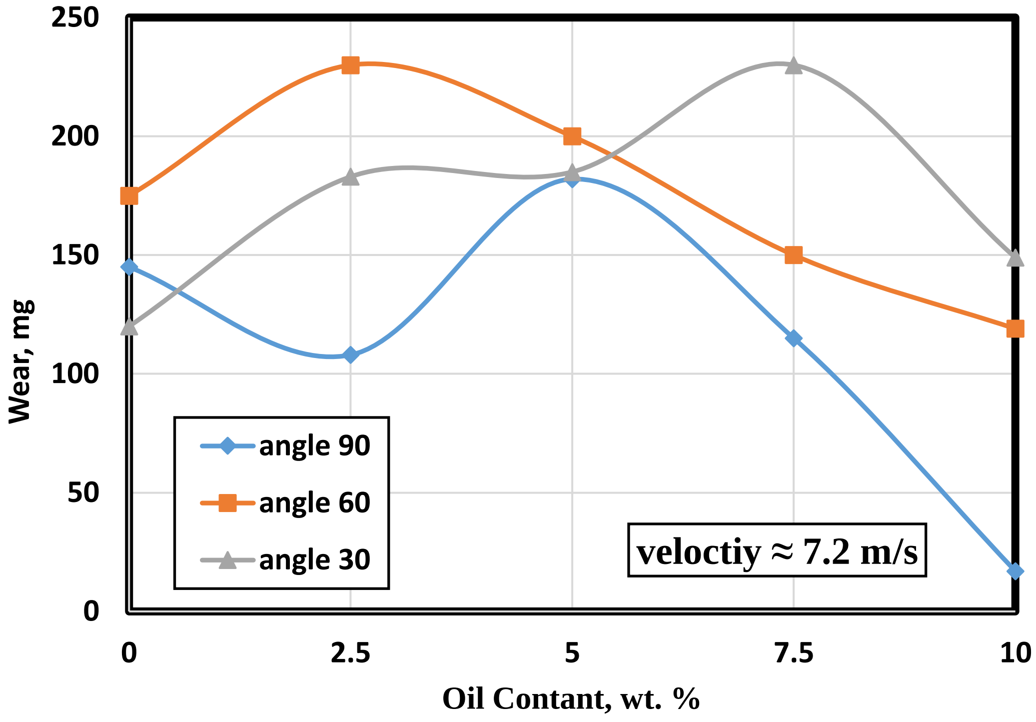


Fig. 8 Relationship between oil content and wear at 7.2 m/s particle velocity.

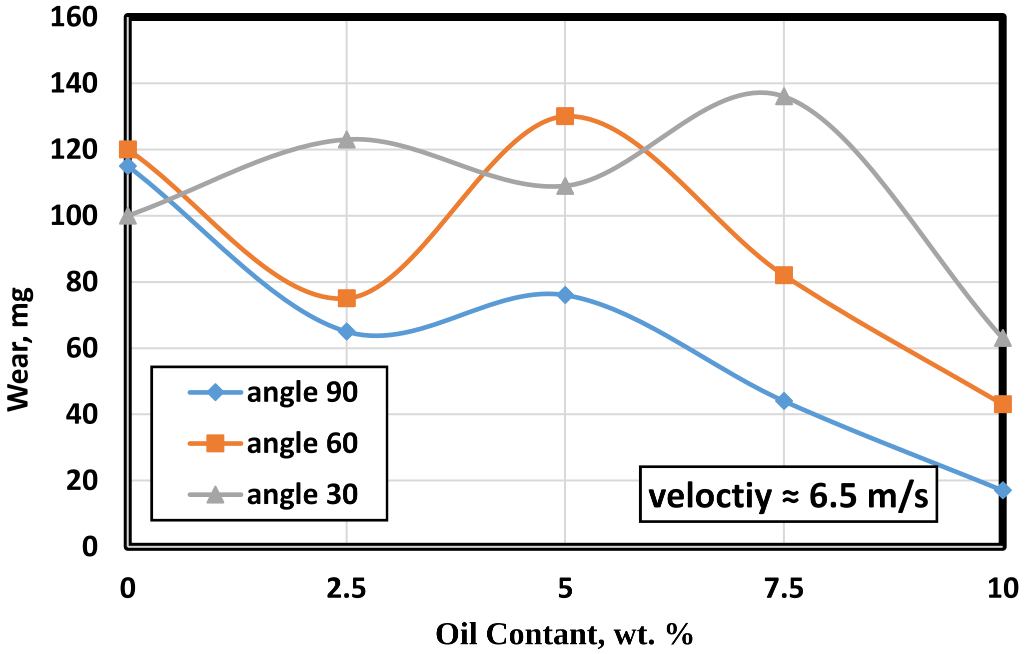


Fig. 9 Relationship between oil content and wear at 6.5 m/s particle velocity.

Figure 9 shows the effect of adding oil to Epoxy/Gf composites on wear at 6.5 m/s calculated impact velocity. It is seen that with increasing oil content wear decreases. The maximum wear takes place at 5 % oil wt.% content. In addition to that, minimum wear occurs at 90° inclination angle. It can be noticed that 5 wt. % oil shows a reversal in wear value for impact angle 30°.

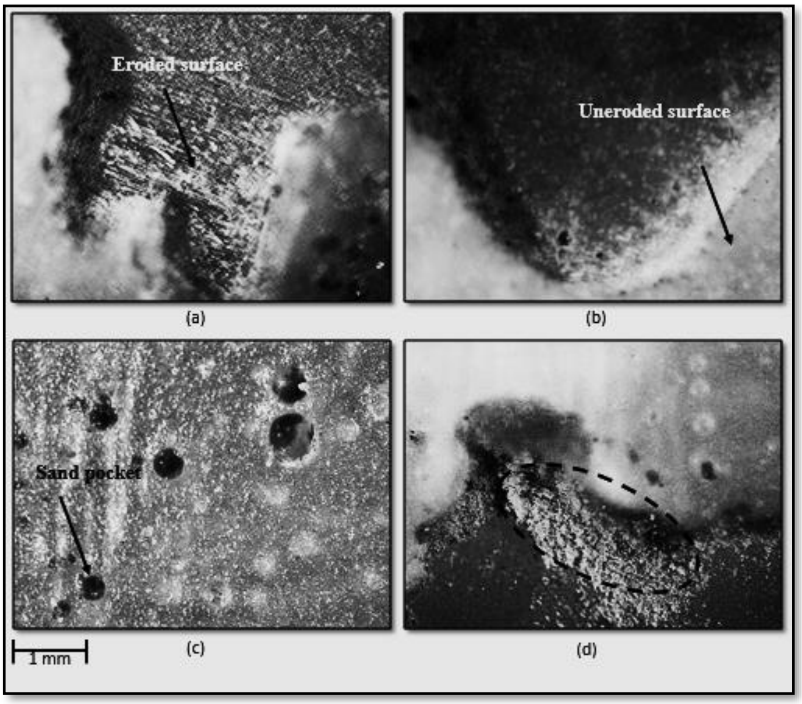


Fig. 10 Microscope photo of specimens after erosion test preform (a) impact angle 30º 7.5 wt. % oil, (b)impact angle 60º 7.5% oil, (c) impact angle 60º 5% oil, (d) impact angle 30º 5% oil

Figure 10 shows the micrographs of surfaces eroded at an impingement angle of 30º and 60º. When impacting at low angles, the hard erodent particles can penetrate the surfaces of the samples and cause material removal by micro-cutting and micro ploughing. It is possible to investigate the particle flow direction easily from the wear trace of the particles, which are indicated in the micrographs as shown in Figs. 10a. As explained above in lower impingement angles, erosive wear happened dominantly in abrasive mode. The higher particle velocity makes the sample surface remarkably rougher compared to the lower particle velocity of Fig.4b at the same impingement angle 30º. Besides, it can be observed from dashed selected area at Fig. 10 c and Fig.10 d that the sand particles were gathered in grooves and pockets made by erosion mechanisms.

In general, thermoplastic matrix composites shows a ductile erosive wear (plastic deformation, ploughing, and ductile tearing), while thermosetting matrix composites erode in a brittle manner. However, this failure classification is not fully definitive because the erosion behaviour of composites depends strongly on the experimental conditions and the structure of the target material. It is well known that impingement angle is one of the most important factors in erosion behaviour. When the erosive particles affects the target at low angles, the impact force can be divided into two components first one is parallel force (F_P) to the surface of the material and the other vertical force (F_v). F_P controls the abrasive and F_v is responsible for the impact phenomenon. At 90º impact angle, the effects of F_v become marginal. It is obvious that in the case of normal erosion all available energy is dissipated by impact and micro cracking, while at oblique angles due to the decisive role of the F_v the damage occurs by micro cutting and micro-ploughing.

CONCLUSIONS

Based on this study performed on the solid particle erosion of the tested composites, the following conclusions can be drawn:

1. Epoxy/Gf composites filled by 10 wt. % oil content improve erosion resistance.

2. The maximum erosion occurred at 2.5 wt. % oil content, while the minimum erosion occurred for composites filled by 10 wt. % oil at 90º impact angle.

3. Increasing oil content for (Epoxy/Gf) changes the behavior of the target material from semi ductile to ductile material.

4. The wear decreases with the decrease of particle velocity.

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