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Effect of Solid Particle Erosion on Glass Fiber Reinforced Acrylonitrile Butadiene Styrene Composites

Mahesh T S[1], Dr Nandeeshaiah[2]

[1,2]*Dr AIT, Dept.of Mechanical Engg., Bangalore-560056, Karnataka, India*

***Abstract*- The objective of the research work was aimed at investigating solid particle impact response of glass fiber reinforced acrylonitrile butadiene styrene (ABS) composites based on Design of Experiments. Experiments were designed considering five main factors such as different glass orientation, velocity of impact, angle of impact, size of impacting particles, and stand-off-distance. The influence of these factors and interactions on Erosion rate was studied using L_{27} experimental lay-out. Implementation of design of experiments and statistical techniques in analyzing the erosion behaviour of composites was discussed.**

***Keywords*- ABS, Solid particle impact, Taguchi technique**

I. INTRODUCTION

In addition to high specific stiffness and strength composites offer extra benefits such as lightweight, easy manufacturing, designer's will in shaping [1]. The anisotropic behavior of fiber reinforced composites can be very useful when creating a composite for a specific application. Therefore, such composites are frequently used in engineering parts in automobile, aerospace, marine and energetic applications [2]. Due to the operational requirements in dusty environments, the study of solid particle erosion characteristics of the polymeric composites is of high relevance. Damage caused by erosion has been reported in several industries for a wide range of situations. Examples have been cited for transportation of airborne solids through pipes by Bitteret.al [3], boiler tubes exposed to fly ash by Raasket.al [4] and gas turbine blades by Hibbertet al [5]. But solid particle erosion of polymers and their composites have not been investigated to the same extent as for metals or ceramics. However, a number of researchers Barkoula et al [1], Tewari et al [6] have evaluated the resistance of various types of polymers and their composites to solid particle erosion. The resistance of polymers to solid particle erosion has been found to be very poor, and in fact it is two or three orders of magnitude lower than metallic materials. Also, it is well known that the erosion rate of polymer composites is even higher than that of neat polymers as reported by Barkoula et al [1].

From the literature review it is observed that experimental analysis on erosion behavior of ABS polymer composite was scarce and also the effect of various parameters on the erosion response was not characterized to the adequate level. The present research was aimed at investigating solid particle impact response of glass fiber reinforced ABS composites based on Design of Experiments using application tool MINITAB-15 and FEA.

II. EXPERIMENTAL STUDIES

Compression molding technique was used for the fabrication of glass fibre reinforced ABS composite laminates. The moving platens of the hot press were heated to a temperature of 180 °C, general grade ABS and E-glass fibres were used as charge during the fabrication. ABS granules and glass fibre sheets were taken in pre-determined weight ratios. A metallic mould of dimension $300 \times 300\ mm^2$ was placed on the bottom platen, a layer of ABS granules was laid inside the mould followed by a layer glass fibre sheets in alternate layers. Then the top platen was kept in place and both the platens were gradually heated to a temperature of 180 ^oC and held at that temperature for about 3 hours. Then, the mould was allowed to cool down to room temperature during which curing of the composites occurs. The obtained $300 \times 300\ mm^2$ sheet of composite was cut to the required dimensions by water jet machining process.

The solid particle erosion experiments were carried out as per ASTM G76 standard on the erosion test rig. Dry compressed air was mixed with the erodent particles. In the present study aluminum oxide particles of different sizes (177 μm, 420 μm and 595 μm) were used as erodent which were fed at constant rate (4 gm/min) from a sand flow control knob through the nozzle tube and then accelerated by passing the mixture through a convergent brass nozzle of 5mm internal diameter. These particles impact the specimens which were held at different angles with respect to the direction of erodent flow using a swivel and an adjustable sample clip.

The velocity of the eroding particles was determined using standard double disc method .The samples were cleaned in acetone, dried and weighed to an accuracy ± 0.1 mg before and after the erosion trials using a precision electronic balance. The process was repeated till the erosion rate attained a constant value called "steady state erosion rate". The ratio of this weight loss to the weight of the eroding particles causing the loss was then computed as a dimensionless incremental erosion rate. The erosion rate is defined as the weight loss of the specimen due to erosion divided by the weight of the erodent causing the loss.

Erosion Results

In the present work, the impact of five such parameters was studied using orthogonal design. The operating parameters and the selected levels were given in Table 1. The tests were conducted at room temperature as per experimental designs, which give the operating conditions under which each erosion test has been carried out each column represents a test parameter and a row gives a test condition which is nothing but combination of parameter levels. Three parameters each at three levels and two parameters each at two levels in a full factorial experiment require 108 runs whereas, Taguchi's factorial experiment approach reduces it to 36 runs only, offering a great advantage in terms of cost and time.

Table 1:
operating parameters and the selected levels

Parameter	Level 1	Level 2	Level 3	Units
Velocity	33	45	66	m/s
Impact angle	30	60	90	degree
Particle size	177	420	595	µm
Stand of distance	100	160	200	Mm
Fiber orientation	0/90	45/90	30/60	degree

Erosion rate (Er) defined as the ratio of mass lost due to erosion to the mass of erodent.

$$\text{Erosion rate} = \frac{\text{Cumulative mass loss of target materials (mg)}}{\text{Impact particles weight (g)}}$$

As for this experimental analysis "Lower is better" (LB) characteristic of S/N ratio transformation was chosen the lowest value of S/N ratio i.e. -46.02 was the best combination for resistance to erosion rate.

III. EFFECT OF IMPINGEMENT ANGLE ON EROSION RATE

Angle of impingement is the most important and widely studied parameter in the erosion study of materials [7, 8]. When the erosion rate is measured as a function of impingement angle, ductile and brittle materials have shown a marked difference in their response. The behavior of ductile materials is characterized by maximum erosion at acute impingement angle (15°–30°). Brittle materials, on the other hand, show the maximum erosion just under normal impingement angle (90°). The reinforced composites unlike the above two categories show a semi-ductile behavior having the maximum erosion rate in the range of 45°–60° [9].

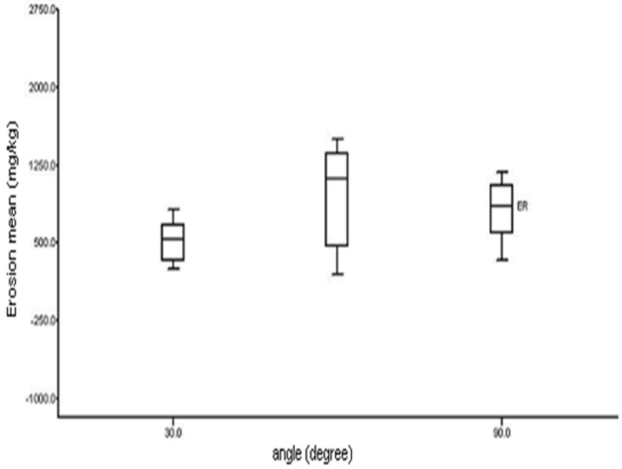

Fig.1: Box whisker diagram of Erosion means v/s angle.

Fig. 1 shows the box whisker diagram of impact angle dependence on the erosion rate of ABS/glass composites with different velocity conditions. The diagram is plotted with the results of erosion tests conducted for different impingement angle for impacting velocity ranging from 33 m/s to 66 m/s. It can be seen that the peaks of erosion rates are located at an angle of 60° for all the samples irrespective of fiber orientation.

Effect Of Fiber Orientation On Erosion Rate

As reported in literature [10], relationship between the fibre directions and particle flow direction has a great importance.

It is reported that the fibers in composites, subjected to particle flow, break in bending if the particle flow direction parallel with respect to the fibre orientation. Bending requires particle indentation into the composite, this indentation induces compressive stresses. At this state, fibre shows a very high resistance to micro bending. These phenomena results in local removal of fibre and resin material from the impacted surface. On the other hand, it is reported that, for transverse particle impact, the particle exerts a lateral loading for the fibers. Because of the lower resistance to bending moment, bundles of fibers get bent and brake easily. This causes high erosive wear at 90° orientation. Also, in case of transverse erosion, high interfacial tensile stresses are generated by particle impacts. This causes intensive deboning and breakage of the fibers, which are not sufficiently supported by the matrix

Fig..2 shows the variation of ABS/glass composite erosion rate with various fiber orientations in the present experiment. The effect of laminate orientation was observed more significant at acute impingement angle because fibers more perpendicular to the particle flow might be broken more easily, allowing particles to abrade more matrix (resin material) of composites. It was also observed that the erosion rate of bidirectional ($0^o/90^o$) was higher than those of bidirectional ($45^o/90^o$) at all impingement angles, while much less fiber direction effect on erosion rate appears at $45^o/90^o$ as shown in Fig2.

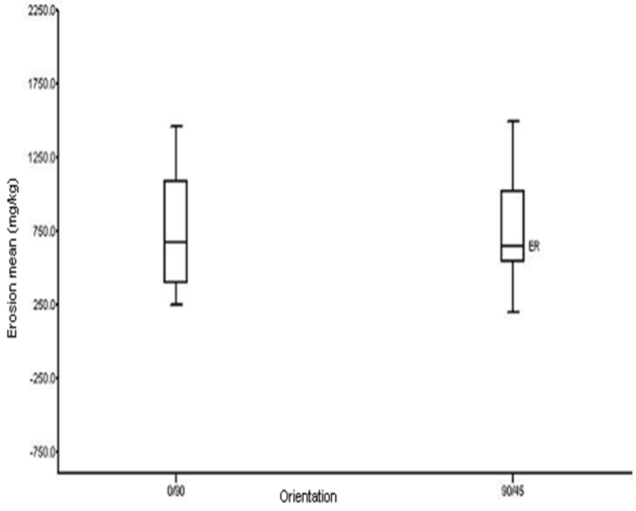

Fig.2.The mass loss of ABS/glass composite as a function of fibre orientation.

Effect Of Velocity Of Impinging Particles On Erosion Rate

Alumina particles, with a 66 m/s speed hit the target material approximately two times faster than the alumina particles with 33 m/s speed. Higher speed means higher kinetic energy. In this case, alumina particles with 66 m/s gives approximately four times higher kinetic energy than particles with 20 m/s according to the kinetic energy equation of $E_k = 1/2*m*v^2$. Fig. 3(a) shows the box whisker diagram mean erosion response of ABS/glass composite as a function of impact velocity. From the results of erosive wear rates in Fig.3(b) for the particle speed of 66 m/s the mass loss at an impingement angle of 90° was approximately 1000 mg/kg and for the particle speed of 33 m/s the mass loss at an impingement angle of 90° was approximately 600(mg/kg). That means the mass loss after erosion at 66 m/s is more than that of 33 m/s and at an impingement angle of 90°. For the particle speed of 66 m/s the mass loss at impingement angle of 30° was approximately 600 mg/kg and for the particle speed of 33 m/s the mass loss at impingement angle of 30° was approximately 300 mg/kg. That means the mass loss after erosion at 66 m/s is two times that for the particle speed of 33 m/s at an impingement angle of 30°.

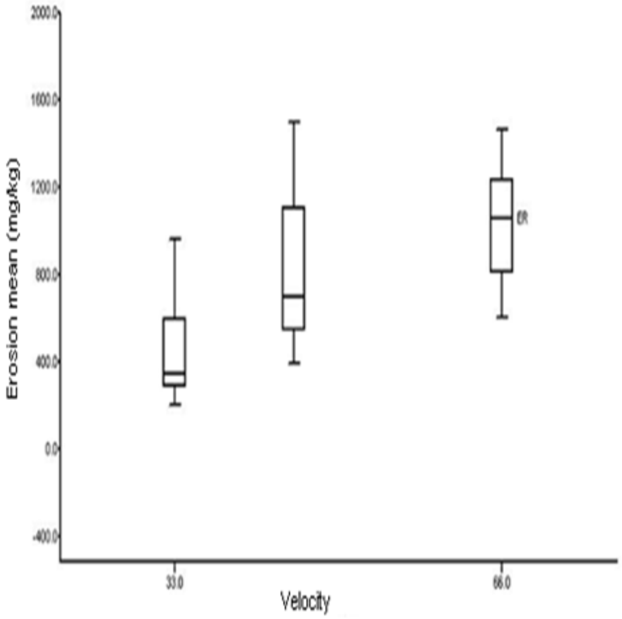

Fig. 3 (a): Box whisker diagram of Erosion means v/s velocity

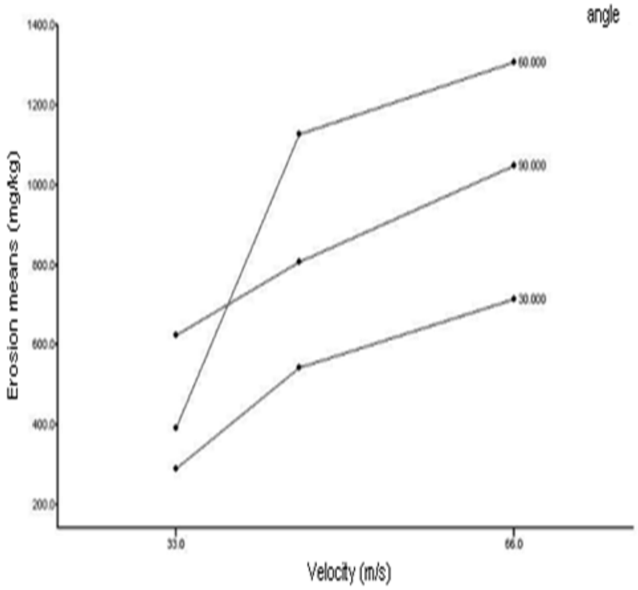

Fig. 3 (b).Erosion mean v/s particle speed as a function of impact angle.

Scanning Electron Micrograph Analysis

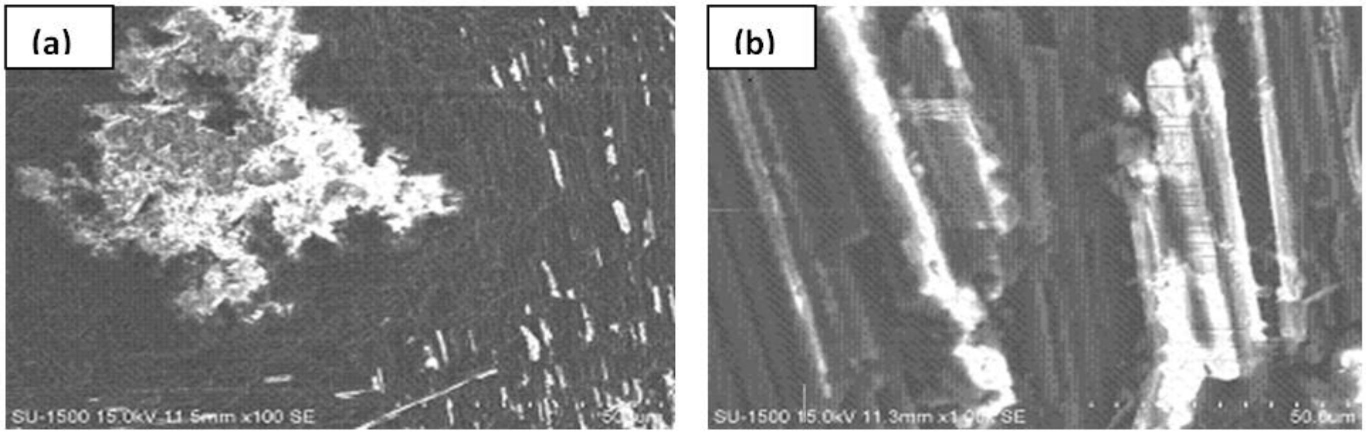

Fig. 4(a) and (b) Scanning electron micrographs of eroded ABS/glass laminate at 66 m/s at an impact angle of 30°.

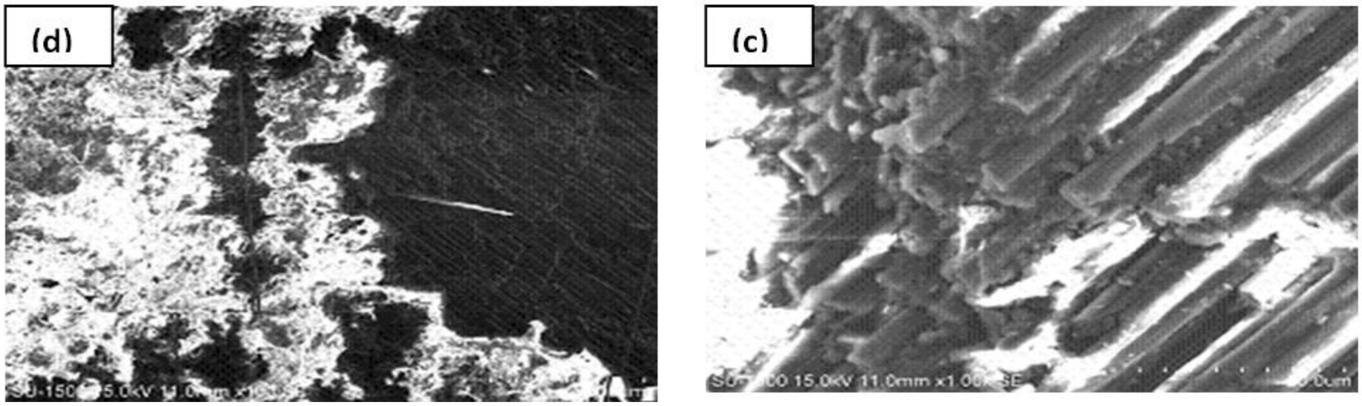

Fig. 5(a) and (b) Scanning electron micrographs of eroded ABS/glass laminate at 66 m/s at an impact angle of 90º.

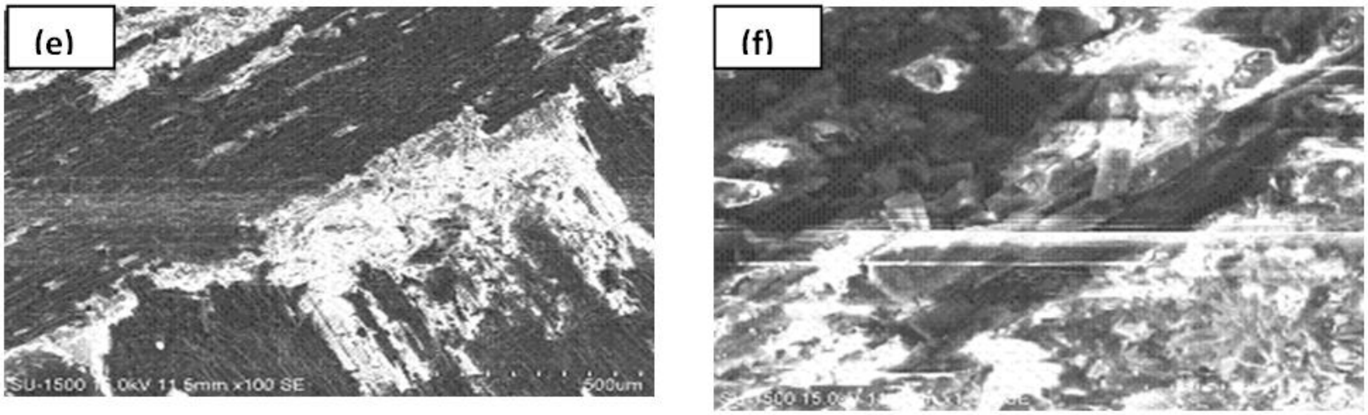

Fig. 6 (a) and (b) Scanning electron micrographs of eroded composite materials surfaces at 60°impact angle at 66 m/s.

Fig. 4, 5 and 6 show the magnified eroded surfaces of ABS/glass laminate impacted at 66 m/s at an impact angle of 30°,90°and 60°respectively. In Fig. 4(a) , the matrix surfaces was observed to be almost flat which sigifies that the erosion of the matrix surfaces has been more or less uniform with exposer of fibers to the surface . Fig. 4(b)(magnified) presents the magnified microstructure of the composite eroded at the same conditon here the propogation of small cracks were well visualized at some points along with small amount of cavitation.

In Fig. 5(a), the cavitation was more and also deeper pits are formed in comparision to the surfaces of the specimen subjected to erosion at an impact angle of 30° and 60°. In Fig. 5(b)(magnified) surface appears like cracks have grown on the fibers giving rise to breakage of the fiber into small fragments,further the cracks have been annihilated at the fibre matrix interface and seen not to have penetrated through the matrix. Fiber breakage was more in this case because of the higher magnitude of the normal component of input velocity, where as in Fig 4 and 5, the tangential component of input velocity was more.

In Fig. 6(a) at 60° the material was removed layer wise and there were origin of cracks which were spread in different direction (multidirectional propogation of cracks)which was observed in magnified Fig. 6(b), intersect one another and form wear debris due to brittle fraction in the fiber body.After repetative impacts, the debris in platelet form are removed and account for the measurement of wear loss.The occurrence of peak erosion rate at 60 impact was observed.In this case ,both abrasion and erosion process plays an important role.After impacting, the particles slide on the surface and abride while dropping down .The wear and subsequently the damage are therfore more than that in the case of normal impact.

Thus change in input angle from oblique to normal changes the topography of the damaged surface very significantly. ABS is a thermoplastic polymer and it is known that it shows ductile erosion response.

So a possible reason for the semi-ductile erosion behavior exhibited by the ABS based composites in the present investigation was that the glass fibers used as reinforcements for ABS matrix are a typical brittle material. Their erosion was caused mostly by damage mechanism such as micro-cracking, micro-cutting and plastic deformation. Such damage was supposed to increase with the increase of kinetic energy loss of the impinging alumina oxide particles. According to Hutchings et al [11], kinetic energy loss was maximum at normal impact, where erosion rates are highest for brittle materials. In the present study, the peak erosion rate shifts to a larger value of impingement angle (60°), which was clearly due to the brittle nature of glass fibers. So, although ABS was a ductile material, the presence of fibers makes the composite relatively more sensitive to impact energy which increases when the impact mode pattern changes from tangential (45°) to normal (90°). This explains the semi-ductile nature of the ABS/glass composites with respect to solid particle erosion.

IV. CONCLUSIONS

- Study of influence of impingement angle on erosion rate of the composites reveals their semi-ductile nature with respect to erosion wear. The peak erosion rate was found to be occurring at 60° impingement angle under various experimental conditions.
- Study of influence of fiber orientation on erosion rate reveals that the erosion rate of bidirectional composite ($0^o/90^o$) was higher than those of bidirectional ($45^o/90^o$)composite at all impingement angles, while much less fiber direction effect on erosion rate appears at ($45^o/90^o$) fiber orientation.
- SEM observation revealed that the material removal was maximum at an impingement angle of 60°, which takes place by micro-cutting, micro-cracking, exposure of fibers and removal of the resin.

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