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Effect of stacking sequence on the erosive wear behavior of jute and jute-glass fabric reinforced epoxy composite

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Abstract

In this present work the effect of stacking sequence on erosive wear behavior of untreated woven jute and glass fabric reinforced epoxy hybrid composites has been investigated experimentally. Composite Laminates were fabricated by hand lay-up technique in a mold and cured under light pressure for one hour, followed by curing at room temperature for forty eight hours. All the laminates were made with a total of 4 plies, by varying the number and position of glass layers so as to obtain six different stacking sequences. One group of only jute laminate was also fabricated for comparison purpose. The erosion rates of these composites have been evaluated at different impingement angles (30-90^0) and at three different particle speeds (v=48, 70, 82m/s).The erodent used is silica sand with the size range 150-250 μm of irregular shapes.The impingement angle was found to have a significant influence on the erosion rate. The composite material showed semi ductile behaviour with maximum erosion at 45^0 impingement angle. The morphology of the eroded surface was examined by SEM.It is conclude from the study that the erosive wear behavior of natural fiber jute can be improved significantly by hybridizing with synthetic fiber glass.

Keywords: Bagasse fiber, SiC abrasive paper, abrasive wear, SEM

1. Introduction

When a local damage caused with material removal by impingement of solid particle against a target surface, material loss occurs, this generally referred to as erosive wear. Popularity of polymer composites in the present scenario is mainly because of their high specific strength and stiffness. These composites are gaining wide acceptance, particularly in aerospace applications for their low weight, high strength to weight ratios and their capabilities to withstand high temperature. However these composites are now getting used in tribo applications such as bearing and gears etc. Being used in applications such as radomes, surfing boats, gas and steam turbine blades, gears of locomotives, conveyer belts, pump impellers in mineral slurry processing, where the components encounter impact of lot of abrasion like dust, sand, splinters of materials, slurry of solid particles and consequently the materials, under go erosive wear (Rajesh *et al*, 2001). The erosive resistance of polymer composite is low in comparison to metallic materials (Roy *et al*, 1994). It is also established that erosive wear of reinforced polymer composite is usually higher than unreinforced polymer matrix (Hager *et al*, 1995). Visualizing the importance of polymeric composites, lot of work has been done to evaluate various types of polymers and their composites to solid particle erosion (Harsha and Thakre, 2007; Tiwari *et al*, 2003; Bijwe *et al*, 2001; Bijwe *et al*, 2002). Most of these workers have carried out wide range of thermoset and thermoplastic PMCs having glass, carbon, graphite and Kevlar fibers in the form of tape, fabric and chopped mat as reinforcement.

Sabeel and Vijayarangan (2008) studied the effect of stacking sequence on tensile, flexural and inter laminar shear properties of woven jute-glass fabric reinforced isothalic polyester composites and reported that incorporation of glass in jute fibre composites enhances the properties of resulting hybrid composites and the layering sequence (altering the position of glass plies) significantly affects the flexural and inter laminar shear strength. Recently, Santulli and Caruso (2009) studied the comparison between two composite architectures namely a hemp/epoxy random mat and a jute/epoxy plain weave laminate, both with 45±2% volume and their work reported that manufacturing a hybrid laminate, using jute/epoxy plain woven and hemp/epoxy random mat, most preferably the latter (inherently stronger) as skins and the former as core, would be able to reduce the scattering in impact resistance values and lead to a better predictability of its impact behaviour.

Srivastava *et al*. (1988) investigated about the fracture toughness and fracture surface energy of epoxy, epoxy/fly-ash, epoxy/carbon, fibre, epoxy/ carbon fiber/fly-ash, epoxy/ glass fiber and epoxy/glass fiber/fly-ash composites. Their results showed that a fly-ash particle can arrest the crack path and thus improve the fracture properties of fiber reinforced plastic (FRP) composites. Miyazaki and Takeda (1993) studied about effect of matrix materials, reinforcement fibers, interface strength between matrix material and fibers, impact angle, and particle velocity on the solid particle erosion behavior of short glass carbon fiber reinforced nylon 66 resin, ABS resin .They found that the erosion rate is larger in FRP, that in neat resin and the erosion rate of FRP decreases with the increase of interface strength between matrix material and fibers.

After reviewing the existing literature available on natural fiber particularly jute fiber it is found that mechanical properties of jute fiber composite are much lower than those of synthetic fiber composite. Another disadvantage which makes jute fiber less attractive is the poor resistance to moisture absorption. Hence use of jute fiber alone in polymer matrix is inadequate in satisfactorily tackling all the technical needs of a fiber reinforced composite.

With this back ground the priority of this work is to develop a superior, but economical composite with jute fiber which can be combined with a synthetic fiber that is glass in the same matrix material so as to take the best advantage of the properties of both fibers. It is also planned to study the mechanical properties and erosive wear behavior of the composite. Resistance to erosive wear is influenced by different factors like particle size (Neville *et al*, 2005), velocity impingement (Sari and Sinmazcelik, 2007), hardness (Hussainova *et al*, 1999), impingement angle (Das *et al*, 1999), fiber length and fiber content (Barkoula and Karger, 2002) and also with the environment (Das *et al*, 2006). Hence, it was thought worthwhile to investigate the erosive wear behaviour of jute and glass fiber reinforced hybrid polymer composite. Based on the above works, the current work aims at finding out the potential of hybridization of jute and glass fiber for tribological applications. The effect of hybridization of glass and layering sequence effect on erosive wear behavior of woven jute-glass fiber hybrid composite is studied.

2. Preparation of Composites

Hybrid laminates of woven jute and glass mat were prepared by hand lay-up technique. The type of epoxy resin used in the present investigation is LY 556which chemically belongs to the 'epoxide' family. Its common name is Bisphenol-A-iglycidyl-Ether. It possesses a density of 1.1gm/cm3. The low temperature epoxy resin and corresponding hardener (HY951) aresupplied by Ciba- Geigy of India Limited. Epoxy is mixed with hardener in the ratio 10:1 by weight. A wooden mold of dimension (150 x 60 x 5) mm was used for casting the composite sheet. A coat of gel was applied on the inner side of the mold and mold release spray was used for quick and easy removal of the composite sheet. Usual hand lay-up technique was used to manufacture the composite sheet of 5 mm thickness at room temperature. The neat resin composite plate was also made with the above dimension without any reinforcement. Suitable pieces of the above were cut from the composite plates for erosion studies. Six groups of laminate composite samples with total 4 plies were manufactured by varying stacking sequence of jute and glass fabrics as presented in Table.1.

Table 1. Laminate stacking sequence

Symbol	Stacking sequence	Wt% of Fibers		Total Fiber		Thickness (mm)
		Jute	Glass	Weight fraction (%)	Volume fraction (%)	
S1	JJJJ	100	00	60.69	54.40	5.0
S2	JJGJ	75	25	65.60	56.36	4.4
S3	JJGG	50	50	66.00	53.33	4.2
S4	JGJG	50	50	57.96	44.80	5.0
S5	JGGJ	50	50	62.73	49.78	4.5
S6	GJJG	50	50	63.79	50.91	4.4
J-Jute ply, G-Glass ply.						

Jute and glass fabrics were pre-impregnated with the matrix material consisting of epoxy resin and hardener in the ratio of 10:1. Care was taken to avoid formation of air bubbles during pouring. Pressure was then applied from the top and the mold was allowed to cure at room temperature for 72 hrs. During the application of pressure some polymer squeezes out from the mould. For this, care has already been taken during pouring. After 72 hrs the samples were taken out of the mold, after curing the laminate was cut into required size of erosion by diamond cutter. In the present case the composites prepared were consists of 62wt% fiber. The total fiber volume fraction is calculated using equation 1.

$$V_f = \frac{(W_j/\rho_j)+(W_g/\rho_g)}{(W_j/\rho_j)+(W_g/\rho_g)+(W_r/\rho_r)} \quad (1)$$

Where *Wj*, *Wg* and *Wr* are the known weights of the jute, glass and resin, respectively, and ρ_j, ρ_g and ρ_r are the densities of jute, glass and resin, respectively. The density of epoxy resin, jute and glass fiber is found to be 1.0974 g/cm^3, 1.42 g/cm^3 and 2.55 g/cm^3 respectively.

3. Erosion wear test

The solid particle erosion experiments were carried out as per ASTM G76 standard on the erosion test rig shown in Figure 1.

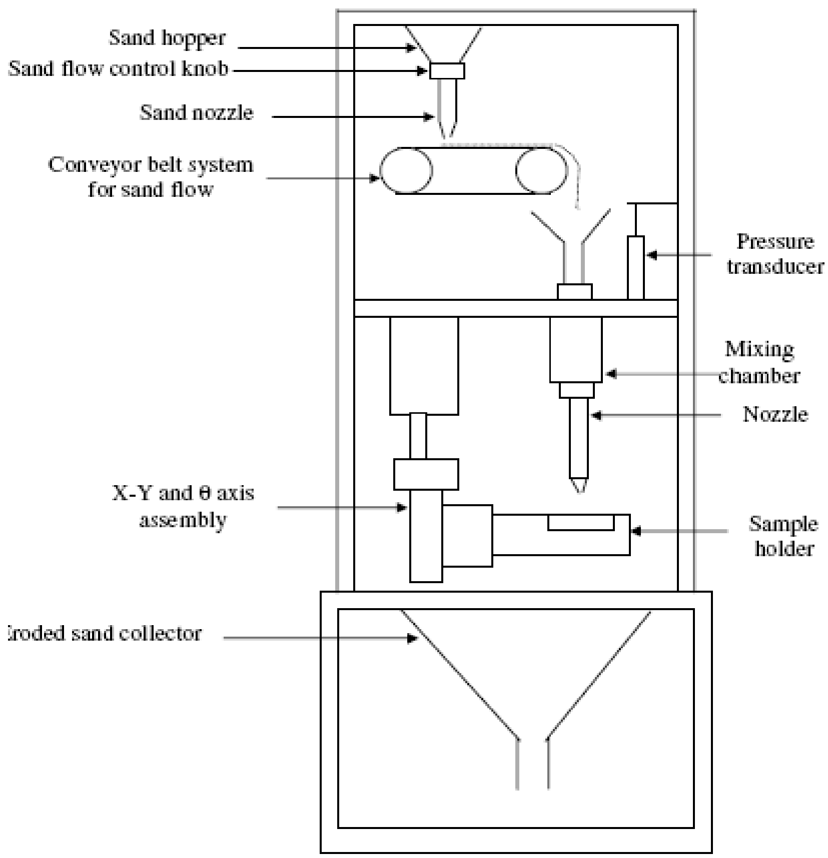


Figure 1. Schematic diagram of erosion test rig

The test rig consist of an air compressor, an air drying unit, a conveyor belt type particle feeder and an particle mixing and accelerating chamber. The dried and compressed air is mixed with silica sand (150-250μm size) which was feed constantly by conveyor belt feeder into the mixing chamber. Samples of composite (30mm x 30mm x 3 mm) were held at selected angles (30^0,45^0,60^0 and 90^0) with respect to flow of the impinging sand particles and eroded. The silica particles were accelerated by passing through a converging tungsten carbide nozzle of 4 mm diameter to bombard the target. The distances between the target material and nozzle was approximately 10 mm. By changing the pressure the compressed air results in the variation of the impact velocity of the particles. The velocity of the eroding particles was determined using a rotating disc method. Wear was measured by weight loss method. Samples were cleaned with acetone before and after each test. Eroded samples were cleaned with a brush to remove fine sand particles attached to the surface and then wiped with a cotton plug dipped in acetone to avoid any air entrapment of wear debris in the samples. The wear rate was expressed in terms of ΔWc (g)/ ΔWs (g); where ΔWc loss of weight of composites and ΔWs total weight of erodent used. ΔWc was determined by weighting the sample before and after each experiment on a weighting balance having an accuracy of 0.001mg. The experimental detail is presented in Table 2.

Table 2. Test parameters

Erodent	Silica sand
Erodent size (μm)	200 ± 50
Impingement angle (α^0)	30, 45, 60, 90
Impact velocity (m/s)	48, 70, 82
Erodent feed rate (g/min)	4
Test temperature	RT
Nozzle to sample distance (mm)	10
Nozzle diameter	4
Time	5min.

4. Microhardness

The present investigation reveals that the by varying the number and position of glass and jute layers six different stacking sequences are obtained. As shown in Figure 2 the composite micro-hardness is different for different stacking sequences. Its maximum value is for sequence S4.

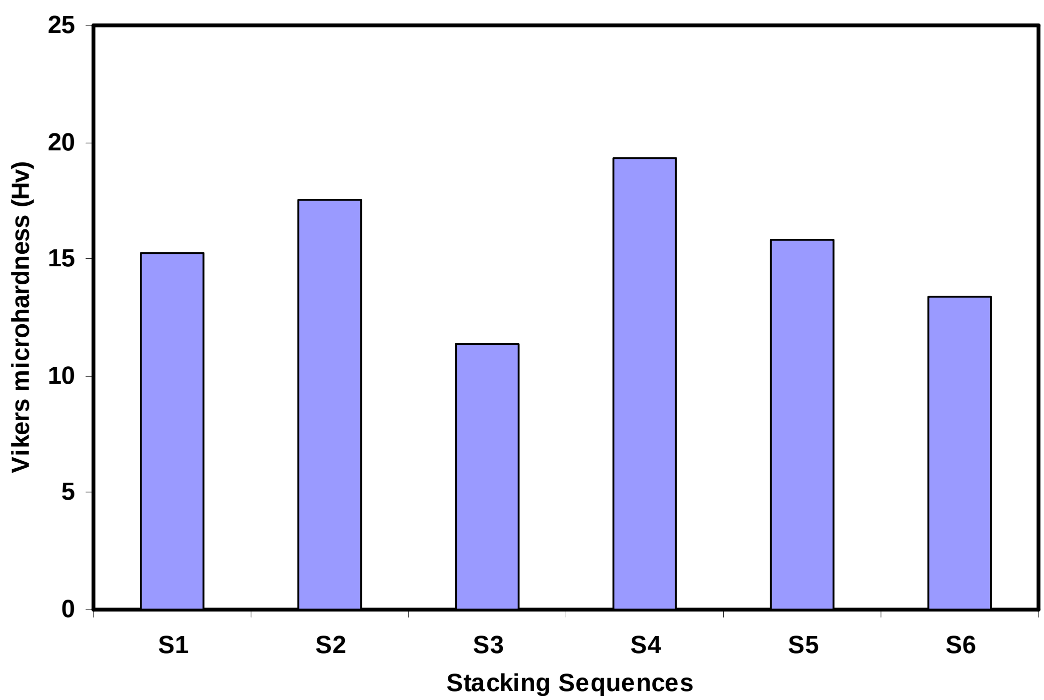


Figure 2. Effect of Hardness on stacking sequence in epoxy composites

5. Influence of impingement angle on erosion wear behavior

Figure 3-5 shows the influence of impingement angle (α) on the erosion rate of jute E-glass epoxy and its composites. This shows that peak erosion takes place at impingement angle of 45^0 for the composites. It is known that impingement angle is one of the most important parameters for the erosion behavior of materials. In the literature materials as classified as ductile or brittle based on the dependence of their erosion rate with impingement angle. The ductile behavior is characterized by maximum erosion rate at low impingement angle typically $15° < \alpha < 30^0$.On the other hand, if the maximum erosion rate occurs at normal impact (α=90^0) the behavior of the material is brittle. Reinforced composites have been found to exhibit semi ductile behavior with maximum erosion rate at intermediate impingement angles; typically ($45^0 < \alpha < 60^0$). However the above classification is not absolute on the erosion behavior of materials which strongly depends upon the experimental conditions and the composition of target materials .Therefore maximum erosion rate at 45^0 in the present case indicates that these composites are neither behaving in a purely ductile nor in a purely brittle manner. So this behavior of these composites can be termed as semi-ductile in nature.

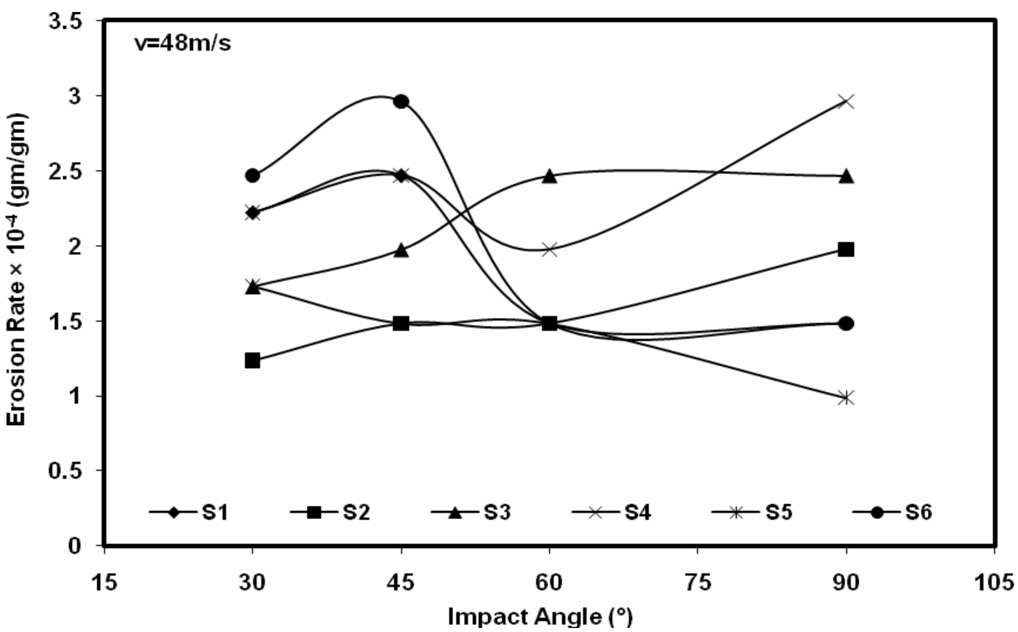


Figure 3. Variation of erosion rate with different impingement angle at velocity 48 m/s

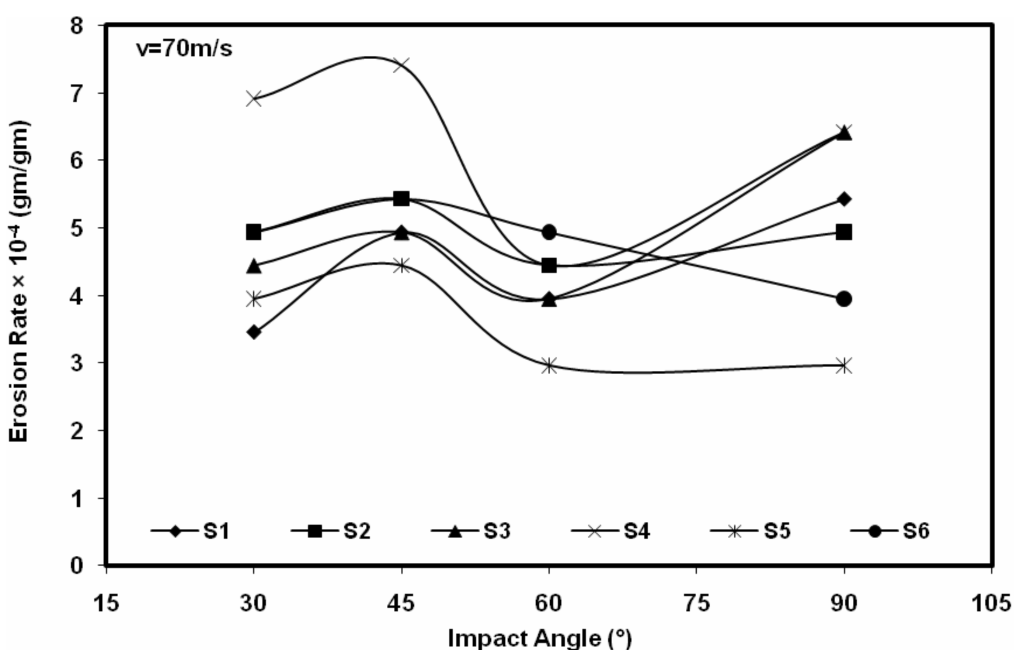


Figure 4. Variation of erosion rate with different impingement angle at velocity 70 m/s

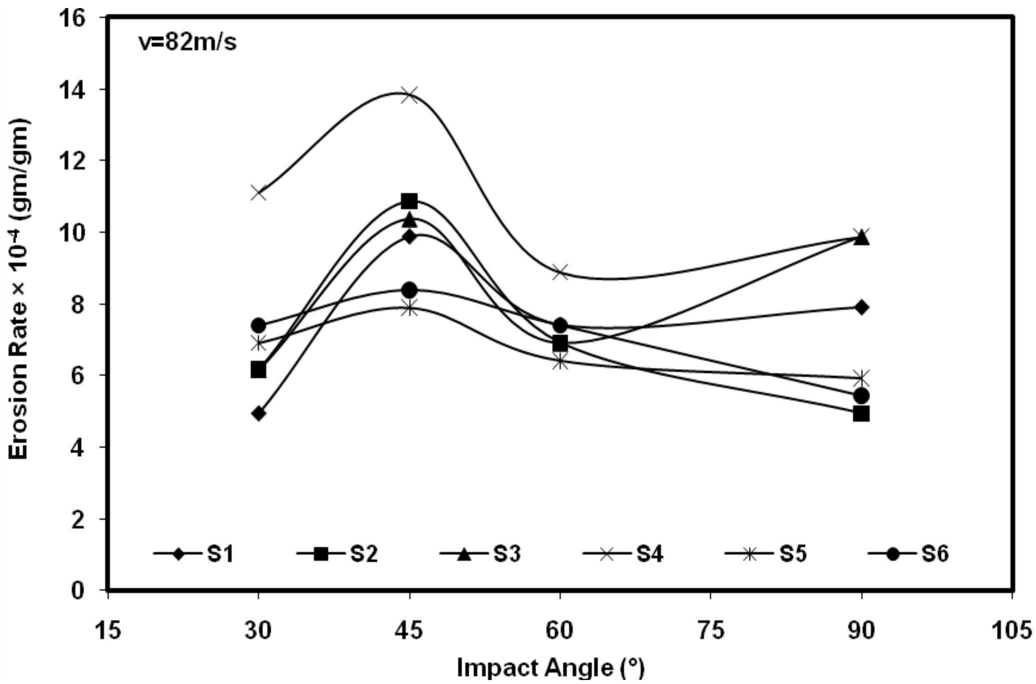
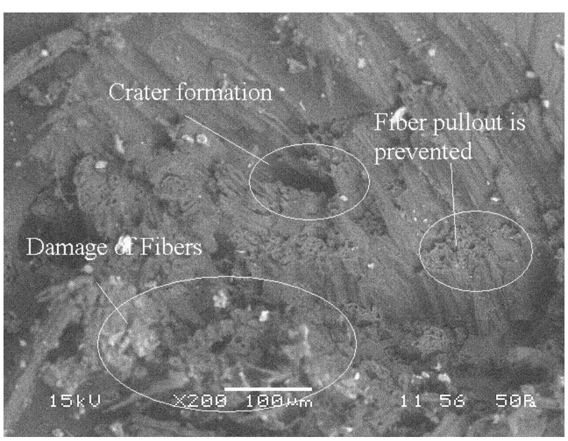


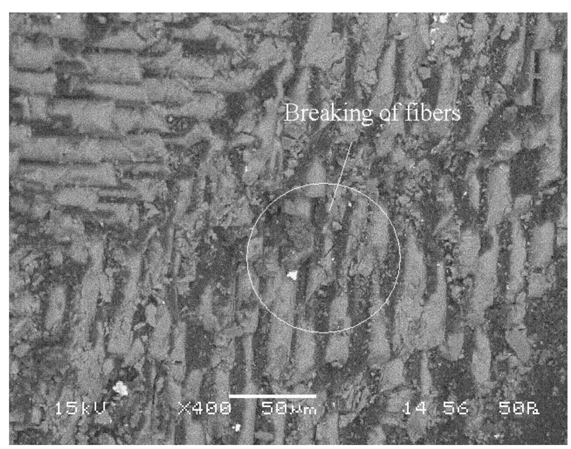
Figure 5. Variation of erosion rate with different impingement angle at velocity 82 m/s

6. Surface morphology of eroded surface

Figure 6 (a) shows the crater formed and the damage caused to the composite. It shows extensive damage of fibers but still fibers are not pullout from the matrix. When the damage enters the glass fiber layers Figure 6(b), it breaks the fibers but chipping up of fibers from the matrix is prevented. It can be justified from this fact that erosion resistance of the natural fiber jute can be improved significantly by placing the synthetic fiber at the middle.



(a) Jute (Extreme layer)



(b) Glass (Intermediate layer)

Figure 6. Micrographs of eroded samples for stacking sequence S_5

7. Conclusion

Experiments were carried out to study the effect of jute and glass fiber stacking sequence on the erosion rate of jute E-glass epoxy and its composites with silica sand as erodent. Based on the results the following conclusions are drawn.

1. Incorporation of glass in jute fiber composite enhances the erosive properties of resulting hybrid composite.
2. Layering sequence (altering the position of glass piles) significantly affects the erosive strength.

3. For the same relative weight fraction of jute and glass fiber, layering sequence has significant effect on erosive wear properties.
4. The erosive wear of sample (S5) with two glass layers between jute layers at extreme ends gives the lowest value.
5. The influence of impingement angle on erosive wear of all composites under consideration exhibit semi ductile behavior with maximum wear rate at 45^0 impingement angle.
6. It is clear from this study that erosive strength of natural fiber (Jute) can be increased by hybridization with synthetic fiber.

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