Effect of stacking sequence on the tribological behaviour of jute-glass hybrid epoxy composite

S. K. Acharya[a]1, Tanusree Bera[a], Ved Prakash[a], Subhrajit Pradhan[a]

[a]*Department of Mechanical Engineering, National Institute of Technology Rourkela, Orissa, 769008, India*

Abstract

In the present work, an attempt has been made to study the three body abrasive wear behaviour of laminate hybrid composites consisting jute fiber/glass fiber reinforced with epoxy resin. The composites samples with different stacking sequence like S1 (GJJJJJJJJG), S2 (GJGJGGJGJG) and S3 (JGJGJJGJGJ) with glass (G) and jute (J) were fabricated using hand layup technique. The three-body abrasive wear behaviour of the designed hybrid composite was carried out as per ASTM G65 standards. The results indicate that the S2 composite exhibits higher wear resistance among the developed composites. The scanning electron microscope (SEM) study was performed for the worn surfaces of the composites to find out the wear mechanism.

Keywords: Jute and Glass fiber, Laminate hybrid composites, Three-body abrasive wear test, SEM.

1. Introduction

An incorporation of more than one type of fiber in a single matrix is called a hybrid composite. The hybrid composite produces high stiffness and strength in comparison to the individual reinforced material. Generally, one of the fiber types is having a low modulus, and cost such as jute, coir, or bagasse, is hybridized with the fiber of high modulus and strength, such as glass or carbon fiber to reduce the use of synthetic fiber. Reduction in use of synthetic fiber with natural fiber to get the same strength and stiffness not only useful from environmental point of view, also reduces the cost of resultant composite. Hybrid composites can provide better strength, high stiffness, enhance the impact and fatigue resistance, and increase the toughness and at the same time reduce the weight and total cost [1]. The performance of the hybrid composites is to balance between the advantages and disadvantages of each individual fiber [2]. Composites can be made by incorporating various natural fibers together, or by an integration of different synthetic fiber, or synthesizing both the natural and synthetic fiber.

There are many researchers who have contributed a lot for the effective design and utilization of hybrid composites. In 2016, Pickering et al. [3] published a review paper based on the mechanical performance of the natural fiber composites. In 2014, Saba et al. [4] released a review paper focusing on the various classes of the natural fiber, nanofiller, cellulosic fiber composites, nanocomposite and natural /nanofiller based hybrid composites and their applications. In 2014, Shalwan and Yousif [5] published a review paper focusing on the mechanical and tribological behavior of natural fiber reinforced with polymer composites. In 2017, Safri et al. [6] published a review paper based on the impact behavior of the natural fiber reinforced polymer composites in the structural system. In 2017, Sanjay et al. [7] published a review paper describing fabrication methods and characterization techniques of natural fiber based polymer composites. In 2018, Sivakumar et al. [8] published a paper on the fatigue behavior of hybrid composites with various fibers configuration. The paper concludes that the thermoset-based hybrid composites give better fatigue resistance in comparison to thermoplastic-based composites. In 2018, Jamir et al. [9] published a paper based on the potential of natural fiber/synthetic fiber hybrid composites for aerospace applications. In 2019, Cihan et al. [10] in their paper explained on the damping and mechanical properties of woven flax/ E-glass hybrid composites. The results conclude that the flax fiber composites, hybrid composites exhibit better damping properties than E-glass fiber composites only when the flax fiber is placed on the outer layer of the hybrid composite samples whereas tensile properties decreases.

It is observed from the literature [5-10] that the research on the three-body abrasive wear test on the laminate hybrid composite with natural fiber and synthetic fiber is not available till date as per knowledge of the authors. Hence, in the present paper, an attempt has been made to find out the wear rate of the laminate hybrid composites with the varying operating parameters such as stacking sequence, load, and speed.

2. Experimental details

2.1. Materials

Woven jute mat and E-glass mat were obtained from Fiber Pilkington Ltd., Kolkata. Araldite LY556 epoxy resin based on diglycidylether of bisphenol A (DGEBA) and HY951 hardener based on Triethylenetetramine Ltd (TETA) were supplied by Hindustan Ciba Geigy Ltd. Mumbai India. The silicon spray was procured from the local supplier.

2.2. Composite fabrication

Hybrid composites of Jute-E-glass fiber/ epoxy composites were fabricated by hand lay-up method. A wooden mold of (76 X 50 X 13) mm^3 was utilized for fabricating the composites. A mold release sheet was placed on the top and bottom layer of the mold for fast and easy removal of the composites. A mold release spray was applied to all the inner wall surface of the mold. Required amount of epoxy resin and hardener (10: 1 ratio by weight) is properly mixed with a mechanical stirrer for 5 min. A small amount of mixture is poured into the wooden mold, jute/glass fiber mat is placed and then an again small quantity of the mixture is poured over the mat as per the designed sequence were placed one by one and the whole mixture was poured into the mold. After placing all the layers in the mold, a roller was used to roll over the fiber to remove voids. Pressure was applied from top of the mold and kept for 72 h for curing. After curing, the composite slab removed from the wooden mold. The same process was continued to fabricate ten layers of the hybrid composite with different stacking sequences of jute-glass/Epoxy Composites. The composites are machined to a dimension of (76 ×25 × 10) mm^3 for further processing. The stacking sequences of the composite along with weight fraction of fibers and thickness of the slab produced are shown in Table 1.

Table 1. Laminate stacking sequence of hybrid composites.

Symbol	Stacking sequence	Jute	Glass	Weight fraction (%)	Thickness (mm)
S1	GJJJJJJJJG	80	20	14.88	10
S2	GJGJGGJGJG	40	60	17.5	10
S3	JGJGJJGJGJ	60	40	18.43	10

2.3. Three-body abrasive wear test

The abrasive wear test of the hybrid composites was carried out by dry sand abrasion test rig designed as per ASTM G65 standard [11]. The test is conducted at room temperature. The specimen was mounted on the specimen holder properly so that it does not vibrate inside it while operation [fig.1]. Proper weights were added subsequently to the lever arm to develop required force to press the specimen against the wheel. Then the lever arm is lowered by the lifting cam in order to press the specimen against the rubber wheel. Sand flow was initiated between the rubber wheel and the specimen during the test period. When proper uniform sand flow occurred the wheel rotation started. The rotation of the abrasive wheel was such that its contacting face moves in the direction same as that of sand flow. The pivot axis of the lever arm lies within a plane, which is approximately tangent to the rubber wheel surface and is perpendicular to the horizontal diameter along which the load is applied. After the wheel has rotated desired number of revolutions the wheel rotation was stopped. The specimen was taken out after each test for measurement of wear.

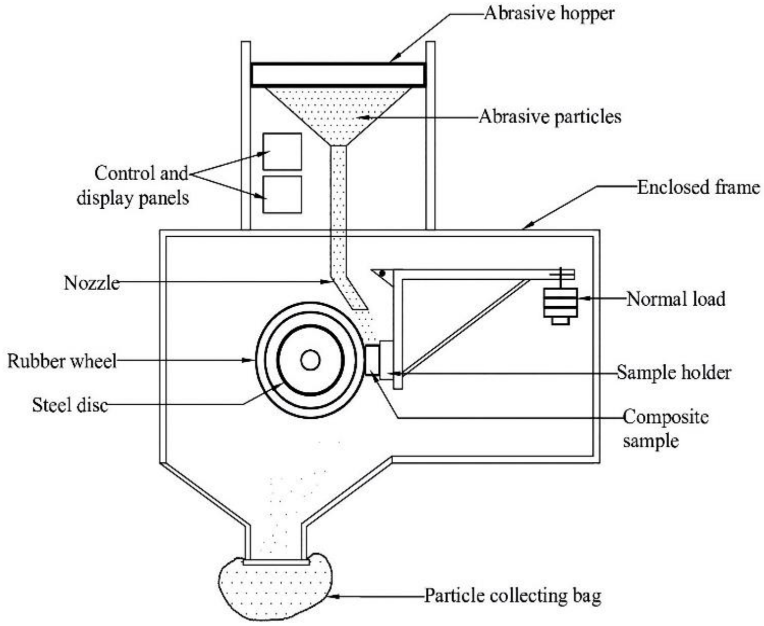

Fig. 1. Schematic diagram of three body abrasive wear test arrangement

3. Results and Discussions

3.1. Effect of load on the wear rate

The effect of various loads on the wear rate is shown in Fig. 2. The wear rate increases with the increase in the load. At 5 N load, the wear rates of the composites are almost similar. The wear rate is in the range of 0 to 0.1 mm^3/gm. But as the load increases to 10 N. The wear rate increase to 0.1-0.3 mm^3/gm. Further, an increase in the load from 10 N to 15 N, the wear rate sharply increases and remains in the range of 0.15 to 0.5 mm^3/gm. The rise in the wear rate of the composites with the increase in the load is because at low load the friction between the specimen and the rubber wheel is less, However, as the load increases the frictional forces increases and hence more loss of the material. Therefore the wear rate of the composites increases. It is observed from Fig. 2 that the S2 composite exhibits high wear resistance than the S3 and S1. It is also seen from Table 1 that more contribution of glass fiber is present in S2 (60 %) which is higher than the other composites (S1 and S3). The wear resistance is in the order of S1 > S3 > S2. The reason is glass fiber has more wear resistant than jute fiber.

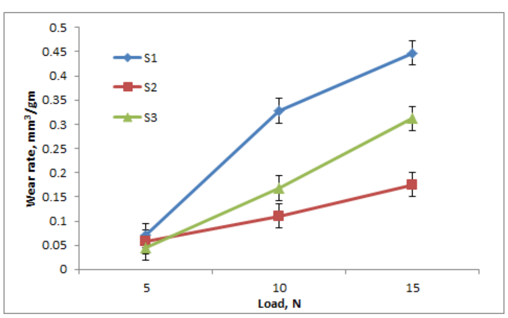

Fig. 2. The influence of the load on the wear rate of the composites

4. Images of the worn hybrid composites

The images of the worn samples of the S1, S2, and S3 hybrid composites are shown in Fig. 3. The worn portions are marked with circles. The worn scars are generally rectangular in shape for all samples.

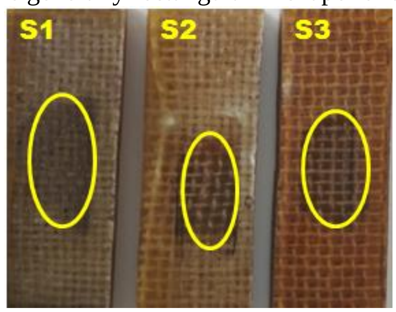

Fig. 3. Images of the worn hybrid composites (S1, S2, and S3)

5. SEM morphology of the hybrid composites

Fig. 4 shows the morphology of the wear out hybrid composites at 300 rpm with 15 N load at 1000X magnification. It has been found that the small wear debris is scattered on the surface of all the composites. The S1 composites, which is having 20% of glass fiber and 80% of jute fiber (Table 1) includes cracks; the crack is started from one point on the surface and propagated to surroundings. The broken fiber is seen in the surface, but it is not so clear with this magnification. It is clearly visible with higher magnification (Fig. 5a). The surface is completely filled with wear debris of matrix and fiber. The S2 composite has good wear resistance, which is clearly visible from Fig. 4b. The wear debris is there but some spaces are less wear debris and clean than the other two composites (S1 and S2). The higher magnification of S2 composites shows the bare fiber (Fig 5b). The worn out of the S3 composite gives a lot of wear debris than S2 but less than S1. Some craters are present on the surface. When we see S2 on higher magnification, exposed fiber is properly visible on the abraded surface (Fig. 5c).

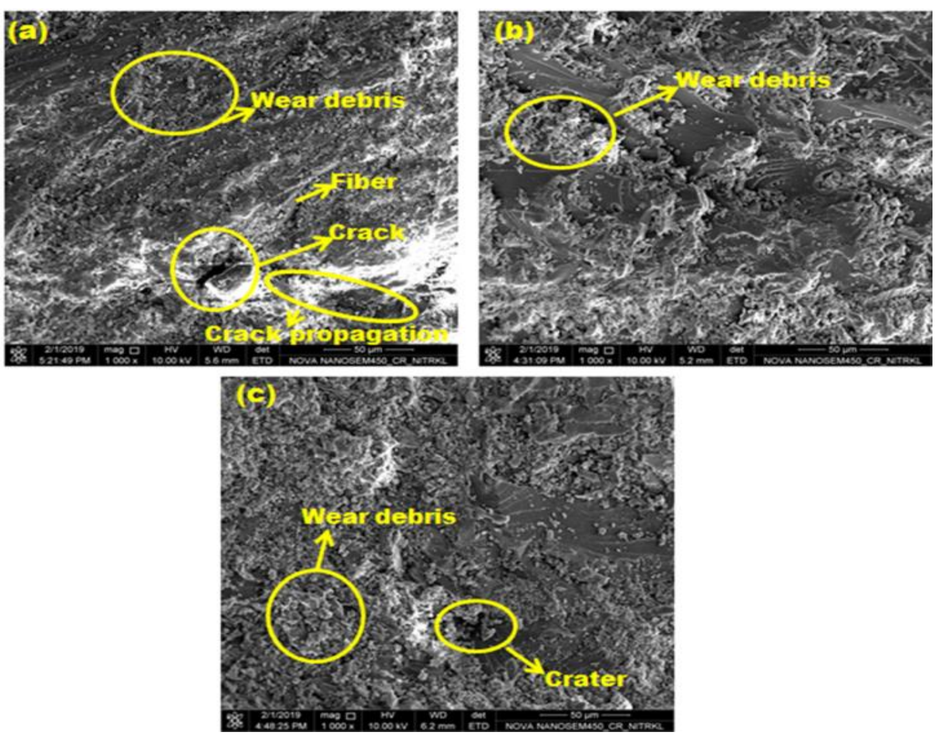

Fig. 4. SEM morphology of hybrid composites after abrasive wear test at 300 RPM with 15 N load at 1000X magnification (a) S1 (b) S2 (c) S3

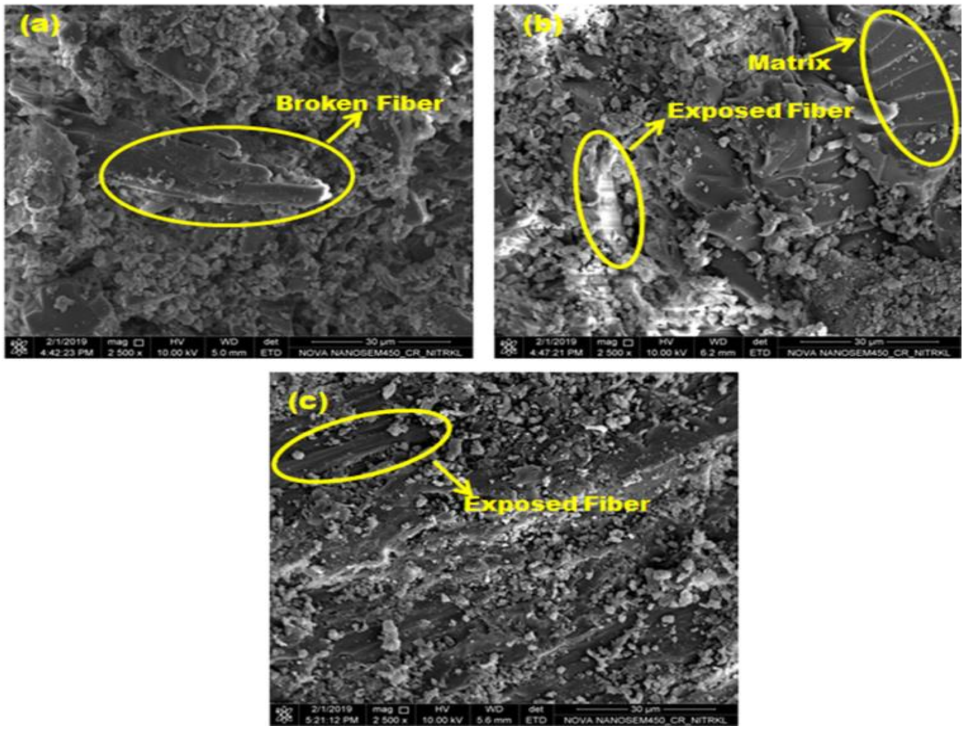

Fig. 5. SEM morphology of hybrid composites after abrasive wear test at 300 RPM with 15 N load at 2500X magnification (a) S1 (b) S2 (c) S3

6. Conclusions

The jute/glass epoxy composites (S1, S2, and S3) with ten layers of laminate hybrid composites are developed. S1, S2, and S3 composites contain 80 %, 40 % and 60 % of jute fiber, whereas 20 %, 60 % and 40 % of glass fiber respectively. The abrasive wear test is carried out on the developed composites. It is concluded that S2 composite exhibits high wear resistance than the S3 and S1. The wear resistance is in the order of S1 > S3 > S2. SEM analysis revealed that the S2 composites have less broken surface compared to S1 and S3.

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