Investigation on 3-body abrasive behaviour of glass fiber and ramie fiber reinforced hybrid Epoxy composites

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Abstract - *This research article presents the investigation of three-body abrasive wear behaviour of glass fiber and ramie fiber reinforced epoxy hybrid composites (HFREC) by varying the proportions of glass fiber and ramie fibers. The hybrid composites was manufactured using hand layup method with the aid of compression moulding technique. The manufactured composites are tailored according to ASTM standards and tested for three body abrasive behaviour with different parameters like composite content, load and sliding distance with the help of L9 orthogonal array with three levels of each parameters to find optimal parameters. From the main effect plots optimal parameters was found to be A3, B1, and C2 gives lowest specific wear rate for HFREC. From the ANOVA table it is clear that sliding distance (P=0.008) is highly significant factor followed by load (P=0.046), and Wt. % of HFREC (P=0.212) was the least influencing factor. The wear surface morphology also studied using scanning electron microscope. From the SEM micrographs micro plaguing, micro-cutting, and micro cracks can be clearly seen. The better wear resistance was seen in Ra10G30 composite.*

Key words: *Ramie Fibers, glass fibers, Hand layup, three-boy abrasive wear, scanning electron microscope,*

1. INTRODUCTION

Natural fibers of different properties and dimensions, produced from plants, animals have been widely used to outfit textile industry demands over the period of time [1]. Like cotton, fibers have been valuable for thousands of years, attained the nickname "white gold." Now a days two are more plant-based materials are being utilised in combinations with different polymer matrices [2, 3]. In the recent times polymer composites outperforming traditional materials in terms of engineering, chemical resistance, biodegradable and replenishable because of their remarkable physical and mechanical properties. The advantages of natural fibers over synthetic fibers are good abrasive nature, lower density, good acoustic properties, less expensive, abundant in nature, readily available and biodegradable [4]. On the other hand Fiber glass in fabric form offers an excellent combination of properties from high strength to fire resistance. Wide ranges of yarn sizes and weave patterns provide unlimited design potential, allowing the end user to choose the best combination of material performance, economics and product flexibility. Fiber glass fabrics are used in a wide range of industrial applications. Fiber glass have some disadvantages like high processing cost non degradable and less resistant to chemicals. In this context the combination of natural and synthetic fibers can be combined in the same matrix to form hybrid composites, which are perfect, superior, and cost-effective [5, 6]. Synthetic– natural fiber hybrid composite research focuses on decreasing the number of artificial fibers. Some of the literatures regarding hybrid composites includes, Joseph et al. [7] tested banana fiber and glass fiber with varying fiber length and fiber content as well. The analysis of tensile, flexural, and impact properties of these composites revealed that composites with good strength could be successfully developed using banana fiber as the reinforcing agent. Amit Bindal et al. [8] developed the hybrid composite consisting of E-glass fabric and treated jute fiber reinforced with polyester composite. The mechanical assessment is carried out on the hybrid composite prepared by hand layup technique by varying percentage of jute-glass fiber content conducting tensile, flexural, impact and the water absorption tests. The test results show that the introduction of jute in the composite has enhanced the mechanical properties. Ramesh et al. [9] studied the mechanical properties and failure morphology of glass-sisal/jute reinforced epoxy hybrid composite taking length of the natural fibers as min constituent. It was reported that the hybridization of glass-sisal reinforced epoxy composite shows good flexural property and the interfacial characteristics of the hybrid composite are analyzed by SEM.Romanzini et al. [10] investigated the effect of fibre hybridization and frequency on the dynamic mechanical characteristics of polyester composites reinforced with ramie/glass hybrid fibres. The storage modulus (E′), the loss modulus (E′′), and the damping behaviour (tanδ) were determined as a function of various glass/ramie fibre volume ratios. The significance of the reinforcing effect above Tg was shown for the storage modulus. Additionally, the peak height, peak breadth at half-height, and relaxation area of the loss modulus and tan δcurves were studied, demonstrating the effect of a shoulder below Tg in each instance. Finally, by increasing the frequency, the tan peak moves to higher temperatures. Higher activation energy was discovered for composites comprising 75% glass fibre.Kapila et al. [11] developed and analyzed pure ramie fabric/epoxy composites as well as its hybrids ramie-glass/epoxy and ramie-basalt/epoxy composites. The research demonstrates that combining natural fibre (ramie) with synthetic fibre (glass) and mineral fibre (basalt) results in a composite with superior mechanical capabilities than pure ramie. Additionally, ramie-glass hybrid composites have a greater tensile strength than ramie-basalt hybrid composites. The defects in the flexural specimen were discovered using a scanning electron microscope (SEM). SEM scans reveal that hybrid composites include fewer defects than pure ramie fabric composites. As a result, it may be deduced that the addition of advanced fabric to the exterior layers of natural fibre composites would increase their strength. From these observations it can be concluded that most of the researchers investigated hybrid composites for mechanical properties and very few studies have been carried out to investigate the three body abrasive behaviour of hybrid composites.

In this context an attempt has been made to develop glass fiber and ramie fiber reinforced epoxy hybrid composites by hand layup method with the aid of compression moulding technique. The manufactured composites are tailored according to ASTM standards and tested for three body abrasive behaviour with different parameters like composite content, load and sliding distance with the help of L9 orthogonal array. The wear surface morphology also studied using scanning electron microscope.

2. EXPERIMENTAL

2.1Materials

Lapox L-12 with the Density: of 1.1-1.2 g/cm3, having a tensile strength of 60-70 MPa at 25˚C and Shell life of 2 years and K6 Hardener was procured from Suntech fibers, Bangalore.E-Glass fibers with 360 GSM was also procured from Suntech fibers Bengaluru. Ramie fibers with the diameter of 25-30 µm andhaving a density of 1.5-1.55 with a tensile strength of 400-600 MPa was procured from Doshi Group Mumbai.

2.2 Processing of composite materials

In the present work a plain weave mat of E-glass fabrics of 0.3 mm thickness as synthetic reinforcement and plain weave mat of Ramie fibers with a diameter of 25-30 µm with thickness of 0.4 mm thickness as a natural reinforcement. The matrix material was Epoxy resin (Lapox L-12)with the Density: of 1.1-1.2 g/cm3 was used to manufacture composites. Hand layup process was employed to manufacture composites as it is less expensive than other manufacturing methods. In the hand layup process firstly, a mould releasing agent is applied on a glass sheet then a layer of resin is applied. Further, alternate layers of ramie fiber mat and glass fiber mat is placed and resin mixed with hardener is applied at every layer of glass fiber mat and ramie fiber mat. This step is repeated until thickness according to the requirements. The hand lay upped layers are then placed in mould and kept in compression moulding machine of 10 ton capacity at 80° C and pressed at a pressure of 24 kg/cm2 for a period of 2 hours. The mould is cured at a room temperature of 24 hours and composite is removed from the mould. The manufactured composite is tailored according to ASTM standards. The specimens then tested for three body abrasive wear behaviour according to ASTM standards. The manufacturing process of composites is as shown in figure 1. The details of specimen composition of composites is given in table 1.

Table 1: Details of specimen composition of composites

Composition	Weight % of epoxy	Weight % of glass fibre	Weight % of ramie fibre
Ra30G10	60	10	30
Ra10G30	60	30	10
Ra20G20	60	20	20

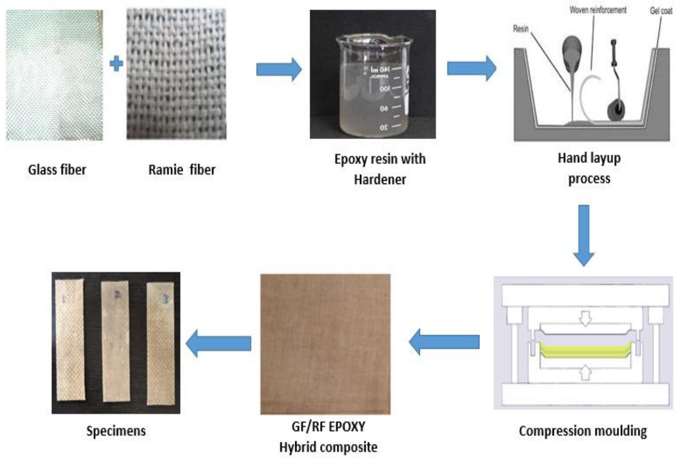

Figure 1. Manufacturing process of GF/RF fiber hybrid epoxy composite

3. EXPERIMENTAL PROCEDURES

A three body abrasive wear test is utilized in the present work to determine the wear rate of the HFREC composite. The abrasive dry sand is introduced between the standard test specimen and rotating chloro-butyl rimmed rubber wheel of a specific hardness and a speed of 345 rpm. The test load is achieved by weight of 580 g.silica sand of size 150-250 µm with sharp edges was used as abrasive. The specimens are washed and dried after each test and then weighted on the scaleswith accuracy 0.0001 g. HFREC specimens subjected to wear test are shown in figure 2.

Figure 2. Worn out specimens of HFREC

3.1 Experimental design

The Taguchi design of experiments was used to reduce the number of experimental runs and to find out the optimum composition of composites. This method is widely used to optimize the quality characteristics with a combination of input parameters. Taguchi method gives the optimal parameter by decreasing the number of trials for a particular combination. This power full tool is employed here to simulate the experimental runs using Minitab 17. Table 2 shows the factors and levels selected for analysis. L9 orthogonal array was chosen with three levels of each parameters. In the Signal to Noise Ratio (S/N) analysis, three types of the quality loss function, that is, lower-the-better, higher-the-better, and nominal-the-better; were obtained. Hence, to get the optimal parameters for wear rate, lower-the-better function was taken as shown in equation 1.

S/N = -10log 1/n(∑▒y^2)..................Equation 1

Where, "n" is the number of observations, and Y is the observed data. Thereafter a statistical analysis of variance(ANOVA) tool was used to identify the optimal combination of the process variables.

Table 2: Process parameters and levels

Level	Process Parameters		
	Wt. % of HFREC (A)	Load (B)	Sliding Distance (C)
1	Ra30G10 (1)	10	0.25
2	Ra20G20 (2)	20	0.5
3	Ra10G30 (3)	30	0.75

4. RESULTS AND DISCUSSION

4.1 Taguchi design of experiments

The experiments were performed according to L9 orthogonal array. The specific wear rate and the corresponding S/N ratio is shown in table 3. The main effect plot for S/N ratio is shown in figure 3 for HFREC composites.

Table 3: Experimental design using L9 orthogonal array

Wt. % of HFREC	Load	Sliding Distance	Initial Weight (g)	Final Weight (g)	Wear Loss (g)	Density	Volume Loss	Specific Wear rate	S/N Ratio of Specific Wear Rate
1	10	0.25	4.836	4.740	0.097	1.284	0.075	0.0195	34.1977
1	20	0.5	4.885	4.583	0.302	1.284	0.236	0.0156	36.0913
1	30	0.75	4.741	4.211	0.530	1.284	0.413	0.0488	26.2309
2	10	0.5	5.023	4.885	0.138	1.410	0.098	0.0147	36.6132
2	20	0.75	4.926	4.594	0.332	1.410	0.235	0.0477	26.4256
2	30	0.25	5.066	4.550	0.516	1.410	0.366	0.0292	30.6910
3	10	0.75	7.235	7.093	0.142	1.282	0.111	0.0301	30.4396
3	20	0.25	7.227	6.921	0.306	1.282	0.239	0.0235	32.5597
3	30	0.5	6.929	6.368	0.562	1.282	0.438	0.0183	34.7327

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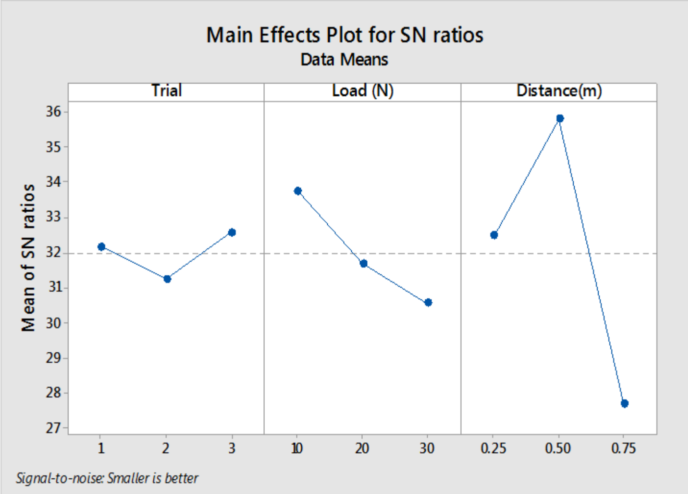

Figure 3. Effect of control factors on the S/N ratio of HFREC composite

From the S/N plots it can be observed that the mean S/N ratio for experimental were found to be 32.06 dB for HFREC composites. The results was analysed at 5% significant level which is denoted by "P". The value of P denotes its contribution on the total variation of the output (SWR). Lower the value of P denotes higher will be its contribution. The order of percentage contribution on wear performance of HFREC is Sliding Distance (P=83.77%)>>>Load (P=13.23%)>>>Wt. % of HFREC (P=2.35%).It is depicted from the figure 3 that factor combination of A3, B1, and C2 gives lowest specific wear rate for HFREC. The specific wear rate results of HFREC are presented in table 3. Outcomes of the similar test conditions is incorporation of ramie fibers along with glass fiber shows much lower wear rate due to the good wear resistant properties of ramie fibers.The analysis of variance (ANOVA) is studied to know the statistical significance of the control parameters. ANOVA is performed for 5% significance level of confidence. Table 4 shows ANOVA results of HFREC. From the ANOVA table it is clear that the factor sliding distance (P=0.008) is highly significant factor followed by load (P=0.046), and Wt. % of HFREC (P=0.212) was the least influencing factor. Last column of table P% shows the percentage contribution of each factor. Therefore it is clear from this analysis, that the incorporation of ramie fibers in a composites shows better mechanical and abrasive wear properties.

Table 4. ANOVA table for specific wear rare of HFREC

S = 0.6141 R-Sq. = 99.4% R-Sq.(adj) = 97.5%							
Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**	**% Contribution**
Wt. % of HFREC	2	2.808	2.808	1.4039	3.72	0.212	2.35
Load	2	15.767	15.767	7.8837	20.90	0.046	13.23
Sliding Distance	2	99.807	99.807	49.9033	132.31	0.008	83.77
Residual Error	2	0.754	0.754	0.3772			0.63
Total	8	119.136					

4.2 Worn surface morphology of HFREC composites

The worn surface morphology of worn out samples was investigated using scanning electron microscope. Abrasive wear often caused by three separate mechanisms: micro-ploughing, micro cutting, and micro-cracking. In three-body abrasive wear, dry and loose abrasive particles are utilized; the material removal rate is determined by a variety of factors that regulate the amount of effort necessary to induce material failure [12, 13].

Worn surfaces of hybrid composites with the compositions Ra30G10, Ra20G20, and Ra10G30 were examined under SEM to comprehend structural changes such as scratches, grooves and smooth surfaces when samples were exposed to load and sliding distance, as shown in Fig. 4 (a-c). This investigation also helps in examining wear conditions and their impact on the fibres and matrix. The SEM micrograph of the Ra30G10 hybrid composite is shown in Fig. 4 (a). During the testing of the composite, a definite failure can be seen, as well as debris. Deep ploughing is generated even when a smaller load of 10N is applied to the composite. This exhibits the ramie/glass fiber-reinforced composite's poor weight bearing capabilities.

Fig. 4 (b) shows the SEM micrograph of Ra20G20at a load of 30N, from the micrograph it is clear that hybrid composite eventually loses top surface however there is no indication of fibre breakdown. However, deboning of the reinforcements and the matrix has only just occurred.

Furthermore, abrasion and cracks are detected on the sample surface that was driven by a greater sliding distance, as well as increased debris accumulation.

Figure 4 (c) depicts the micrograph of Ra10G30 sample. From the micrograph it is found that lowest wear rate obtained in Ra10G30 composite with the maximum sliding distance less wear debris can be seen [14]. Also there is a good registry between fibre surfaces with the matrix, which may be the reason for the exceptional wear resistance found in the hybrid composite. This finding was consistent with previous study findings, which stated that the incorporation of glass fibre is encouraged for natural fiber-based polymer composites in order to improve the wear behaviour of the composites [15, 16]. Thus, strong adhesion between the reinforcements and the epoxy matrix, as well as the stiffness of the fibre, may be ascribed to a substantial decrease in the wear rate of these composites.

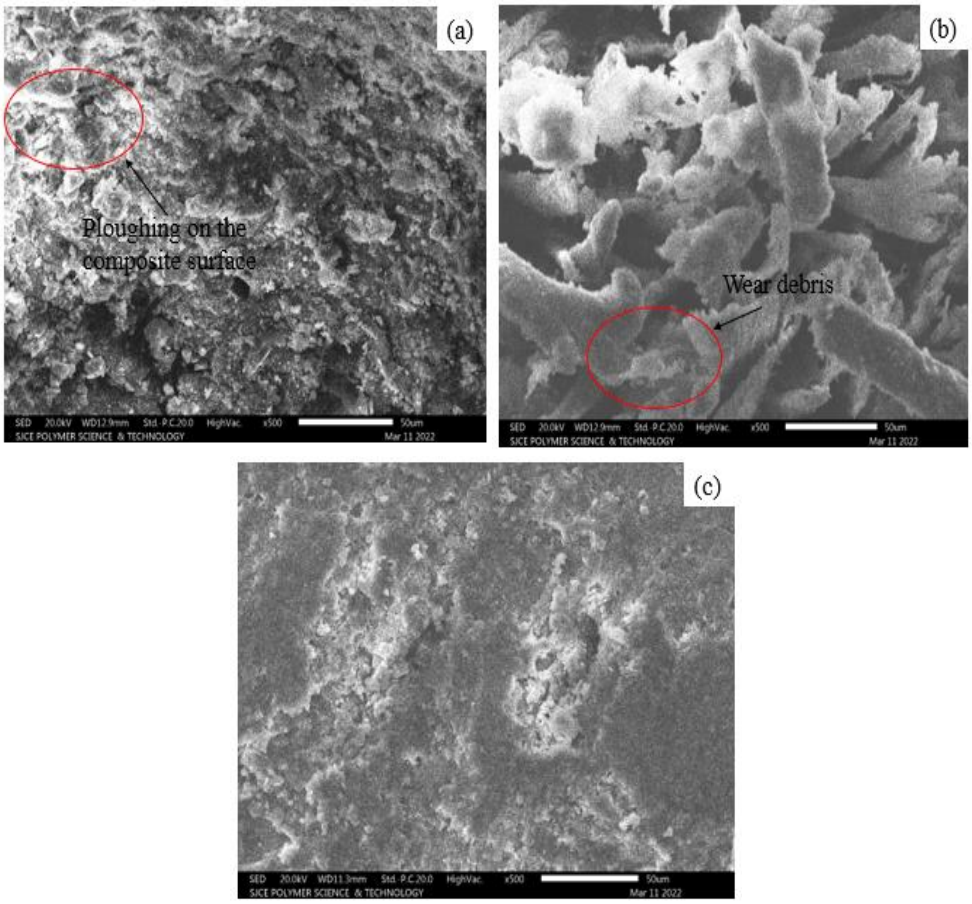

Fig. 4 (a-c): SEM picture of worn surface of HFREC - 4(a) Ra30G10, 4(b): Ra20G20, 4(c) Ra10G30

5. CONCLUSION

In this research glass fiber and ramie fiber reinforced epoxy hybrid composites was developed by hand layup method with the aid of compression moulding technique. The manufactured composites are tailored according to ASTM standards and tested for three body abrasive behaviour with different parameters like composite content, load and sliding distance with the help of L9 orthogonal array. The wear surface morphology also studied using scanning electron microscope. The following conclusion can be drawn.

- From the main effect plots optimal parameters was found to be A3, B1, and C2 gives lowest specific wear rate for HFREC.
- From the ANOVA table it is clear that sliding distance (P=0.008) is highly significant factor followed by load (P=0.046), and Wt. % of HFREC (P=0.212) was the least influencing factor.
- From the SEM micrographs it was observed a perfect registry between glass fibers/ramie fiber and the epoxy matrix.Also the wear mechanisms like micro plaguing, micro-cutting, and micro cracks can be clearly seen. The better wear resistance was seen in Ra10G30 composites.

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