Physico-Mechanical and Tribological Properties of Glass Fiber Based Epoxy Composites

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***Abstract*—Polymeric materials reinforced with synthetic fibers like glass, carbon, and aramid provide advantage of high stiffness and strength to weight ratio as compared to conventional materials like wood, concrete etc. In the light of these the present experimental study aims at learning the physico-mechanical and tribological properties of glass epoxy composite filled with a filler of MoS_2. Hand layout technique is employed for preparing the samples, with varying weight fraction of bi-directional glass fiber. The ratio of filler is varied between 0 to 6 wt.-%. Specimens were cut from the fabricated laminate according to the ASTM standards for different experiments. The systematic experimentation leads to determination of significant process parameters and material variables that predominantly influence the wear rate. It has been found that wear rate increases with increasing abrading distance and for 4% filler optimized wear strength were achieved. Mechanical properties of composites are increases with increase of filler. The mechanical and wear behaviour of filled composites is more superior then unfilled composites.**

***Index Terms*—glass fiber, mechanical properties, MoS2 filler, tribological properties.**

I. Introduction

Bi-directional glass fiber reinforced polymer composites is widely used in many industrial applications due to several advantages such as low weight, ease of processing, price and noise suspension. The performance of the composites can be further improved by adding particulate filler to them. The "filler" play an important role for the improvement in performance of polymer composites. Filler materials are generally used to reduce the cost of material and to improve mechanical properties to some extent and in some cases to improve its process ability. Besides this, it is also used to increase the properties like reduce shrinkage, hardness and wear resistance [1][2]. Fibre reinforced polymer composites containing different filler are used in many application in which tribological and mechanical properties are critical issues [3][4][5]. Also a full understanding of the effects of all system variables on the wear rate is necessary in order to undertake appropriate steps in the design of machine or structural component and in the choice of materials to reduce/control wear [6].

Many researchers are worked on glass/carbon fibers reinforced epoxy composites and they find optimized values with the addition of fillers[7][8][9].

Most of the researchers are used Sic and graphite as filler due to his unique properties and optimized results with the addition of fillers[10][11][12]. Syed Murtuza Ali et al., [13] studied mechanical and abrasive wear behaviour of coleus spent filled unsaturated polyester/polymethyl methacrylate semi interpenetrating polymer network composites. From the study they found that, Mechanical and wear properties for 5 and 10% w/w bio-based coleus spent (CS) filled and unfilled semi interpenetrating polymer network composites of unsaturated polyester/polymethyl methacrylate (80/20) have been studied. The CS filler lowered the mechanical properties and improved abrasion resistance of USP/PMMA SIPN. The wear volume loss increases with increased abrading distance/load. CS filled USP/PMMA SIPN composites showed better abrasion wear resistance as compared to unfilled USP/PMMA SIPN. B Suresha et al.[14] evaluated mechanical and three-body abrasive wear behaviour of three-dimensional glass fabric reinforced vinyl ester composite. Wear volume loss were found to increase and that of specific wear rate decrease. 3-D glass woven fabrics in vinyl ester (G_{3D}–V) have significant influence on wear under varied abrading distance/loads. G_{3D}–V composite exhibited lower wear rate compared to 2-D glass woven fabric reinforced vinyl ester (G_{2D}–V) composite. B N Ravi Kumar et al., [15] investigated abrasive wear behavior of nanoclay-filled EVA/LDPE composites. NC-EVA/LDPE composites with and without compatibilizer were prepared by Brabender Co-Twin extruder and poly(ethylene-co-glycidyl methacrylate) was used as the compatibilizer. Wear volume loss is increased with increase in abrading distance and the specific wear rate decreased with increase in abrading distance. NC-EV A/LDPE with compatibilizer composite exhibits good abrasive wear resistance compared with NC-EVA/LDPE without compatibilizer. B Suresha et al., [16] studied three-body abrasive wear behavior of filled epoxy composite systems. The epoxy composites were fabricated with 0–20 wt% of the boron carbide in steps of 5 wt%. The filler additions have shown significant influence on three-body abrasive wear behavior at different loads. Inclusion of boron carbide filler in particulate form into epoxy matrix showed improved abrasion resistance.

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Rashmi Balu et al., [17] studied dry sliding wear behavior of organo-modified montmorillonite filled epoxy Nano-composites using Taguchi's techniques. An orthogonal array (L9) was used to investigate the influence of tribological parameters. Results indicate that the sliding distance emerges as the most significant factor affecting wear rate of epoxy nanocomposites. Inclusion of 5 wt.% OMMT nanofiller increased the wear resistance of the epoxy nanocomposite significantly. The worn surfaces of the samples were analyzed by SEM to study the wear mechanisms and to correlate them with the wear test results. Veena M G et al., [18] evaluated the tribological and electrical properties of silica-filled epoxy nanocomposites. To enhance the interfacial interaction between the fillers and the matrix, nanoparticles were pre-treated with silane coupling agent. It is observed that 10 wt% loading of silica is very effective in reducing the wear loss. Further increase in silica increases the wear rate. The influence of silica particle loading on epoxy is evident in the results of electrical parameters like dielectric strength, arc resistance and tracking resistance. There was an improvement in properties up to 15 wt% of filler loading and beyond this noticeable deterioration was observed. B Suresha et al., [19] evaluated friction and dry sliding wear behavior of carbon and glass fabric reinforced vinyl ester composites. Composites were fabricated by the injection moulding technique. At 40% SGF reinforced TPU composite exhibited lower friction coefficient and wear rate than 20 and 30% SGF reinforced TPU composites. The COF and wear rate of the composites decreased with increase in SGF content. He also studied the role of micro/nano fillers on mechanical and tribological properties of polyamide66/polypropylene composites [20]. Composites were fabricated using a twin-screw extruder followed by injection moulding. Tensile and flexural strength of NC + SCF filled PA66/PP was higher than that of PA66/PP blend. Inclusion of micro and nanofillers reduced the wear rate of PA66/PP blend. The wear rates of the blends with micro/nanofillers vary from 30–81% and lower than that of PA66/PP blend.

Although a great deal of work has been reported in the literature which discuss the mechanical and wear behaviour of fiber reinforced polymer composites with and without filler, however a very less work has been done on effect of MoS_2 filler on mechanical and wear behaviour of bi-directional glass fiber reinforced epoxy composites. Against this background, In the present investigation, Composites samples are made by using simple hand-lay-up technique with varying weight fraction of bi-directional glass fiber and MoS_2 filler. The effects of fiber loading and filler on the tribological and mechanical behaviour of epoxy composites are studied.

II. Specimen and Experimental Setup

The fabrication of the various composite materials is carried out through hand layup technique. The composite fabrication consist of three steps: (a) mixing of epoxy resin and filler using a mechanical stirrer, (b) mixing of the curing agent with the filled epoxy resin, and (c) fabrication of composites. Resin and hardener (HY 951) mixed in a ratio of 10:1 by weight as recommended. MoS_2 powder of average size 100-200 µm mixed with epoxy resin by stirring at room temperature and poured in to the wooden mould of dimension (210X210X40) mm^3. The composite sample of three different compositions samples i.e. Sample EG-1 (60% glass fiber + 40% epoxy), sample EG-2 (60% glass fiber + 38% Epoxy + 2% Filler), EG-3 (60% glass fiber+ 36% Epoxy + 4% Filler). The cast of each composite is cured under a load of about 20 kg for 24 hours before it is removed from the mould. Then this cast material is allowed for post curing in the air for another 24 hours after removing out of the mould. Test specimen of 3mm thickness and 50mm length are cut from composite sheets for airjet erosion test. Test specimen of 76 mm length and 25.4 mm width are cut from composite sheets for wear test. After fabrication the test specimens were subjected to various mechanical tests as per ASTM standard. Generally flat specimens are used for tension test. A uniaxial load is applied through both the ends. The dimension of the samples for the test is 150 mm X 10 mm and thickness of approximately 3mm. The test is performed in the universal testing machine and the test is repeated three times for each sample to obtain the mean value of tensile strength. The abrasion testing of composite specimens is performed on a standard abrasion test rig (supplied by DUCOM) as per ASTM G-65 standard and air jet erosion test as per ASTM G76. The material losses from the composite surface are measured by using precision electronic balance.

III. Discussion

A. Density

The theoretical and measured densities along with the corresponding volume fraction of voids were presented in Table I. It was clear from the Table I that the volume fraction of voids was negligible, and this was due to the absence of particulate fillers. With the addition of filler materials more voids were found in the composites. As the filler content changes from composites to composites the volume fraction of voids was also found to be changed.

TABLE I. Theoretical and Measured Density Values of the Composites with Volume Fraction of Voids

Composites	Measured Density (g/cc)	Theoretical Density(g/cc)	Volume fraction of Voids
EG-1	1.52	1.54	0.902
EG -2	1.65	1.72	4.126
EG-3	1.65	1.71	4.817

Density of a composite depends on the relative proportion of matrix and reinforcing materials and this was one of the most important factors determining the properties of the composites. The voids significantly affect some of the mechanical properties and even the performance of composites in the place of use. Higher void contents usually mean lower fatigue resistance, greater susceptibility to water penetration and weathering.

B. Tensile Properties

Tensile test was conducted on the Hounstill's universal testing machine in accordance with ASTM D638. Table II shows the details of the same.

TABLE II. TENSILE TEST RESULTS

Sl.No	Specimen	Max. Load(N)	Tensile stress at maximum load (N/mm²)	Extension at max load (mm)	Extension at break (mm)	Tensile strain at break (%)	Modulus (N/mm²)
1	GE-1	16377.3	418.08	4.23	4.27	8.53	7416.49
2	GE-2	18430.75	455.37	4.86	4.88	9.76	6582.03
3	GE-3	18986.3	476.72	4.91	4.92	9.84	5831.87

In this study, percentage of elongation, tensile strength and tensile modulus at fracture of unfilled and MoS_2 filled glass fiber reinforced epoxy composites are plotted as a function of MoS_2 filler and the same is shown in Fig.1, 2 and 3. Fig.1 shows the percentage elongation of glass fiber reinforced epoxy composite with and without MoS_2 filler. It is observed that, the glass fiber reinforced epoxy composites with 4% MoS_2 filler has highest elongation of 4.92mm and glass fiber reinforced epoxy composite without MoS_2 filler the elongation is 4.27. Fig.2 shows a linear increase in the tensile strength as the percentage of MoS_2 increased. The tensile strength of composite without filler and with 2% and 4% of the MoS_2 content has been increased from 418.08 Mpa to 476.72 Mpa. The tensile modulus from fig.3 shows that, decrease in modulus as the filler content in the composite is increased. These observations suggest overall improvement in tensile properties with the addition of MoS_2 filler.

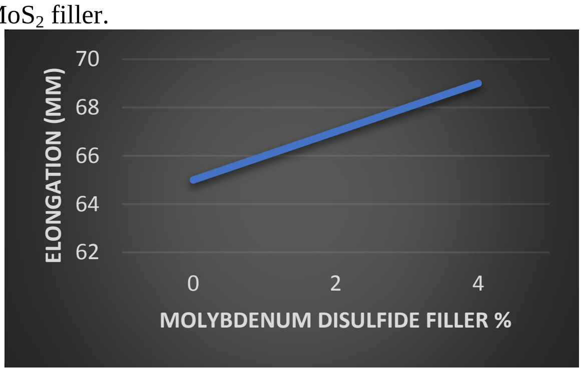

Figure 1. Percentage elongation as a function of MoS2 filler content.

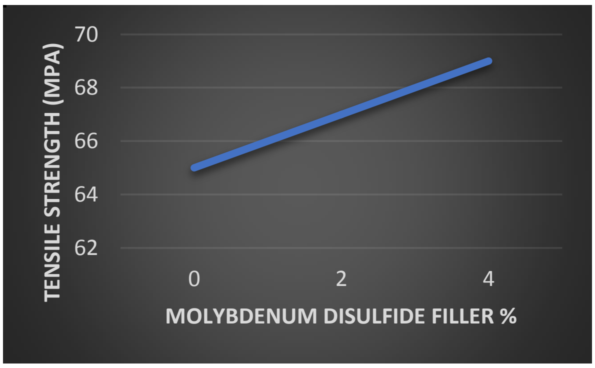

Figure 2. Tensile strength as a function of MoS2 filler content.

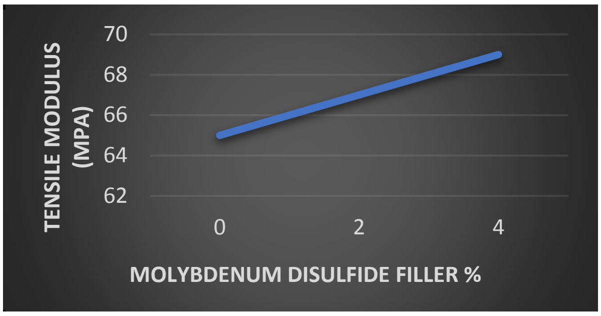

Figure 3. Tensile Modulus as a function of MoS2 filler content.

C. Flexural Properties

TABLE III. FLEXURAL TEST RESULTS

Sl.No	Specimen	Support Span (mm)	Max. Load(N)	Max stress (N/mm²)	Flex modulus(N/mm²)
1	GE-1	50	679.54	466.64	37757.46
2	GE-2	50	1022.33	583.06	41408.63
3	GE-3	50	654.32	398.76	33979.37

Fig.4 and 5 shows the variation of flexural strength and modulus as a function of MoS_2 filler. Glass fiber reinforced epoxy composite with 4% MoS_2 additives showed the least flexural strength and modulus. Whereas the one with 2% of MoS_2 filler indicated the maximum value suggesting that if flexural properties are important in any application, one should use minimum filler content. (Table III)

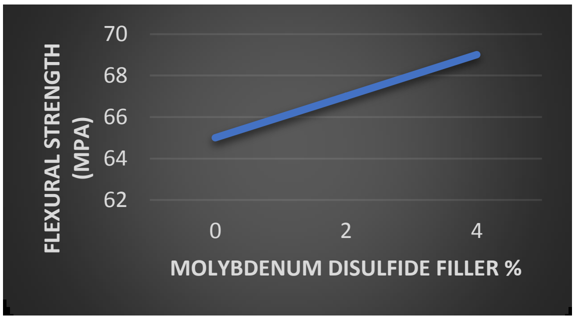

Figure 4. Flexural Strength as a function of MoS2 filler content.

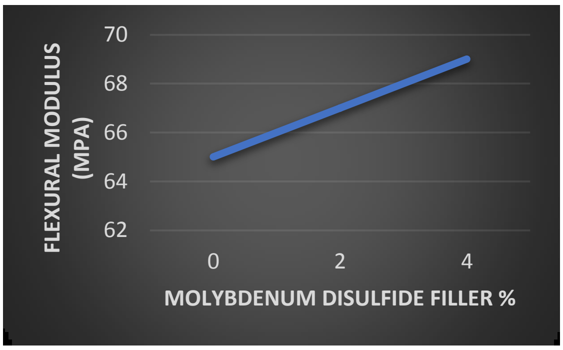

Figure 5. Flexural modulus as a function of MoS2 filler content.

D. Hardness Properties

TABLE IV. HARDNESS TEST RESULTS

Sample no	GE-1	GE-2	GE-3
1	65	67	69
2	65	67	69
3	65	67	69

Hardness test was conducted according to ASTM D-2240 and the readings are tabulated in Table IV. Shore D Hardness number of glass fiber reinforced epoxy composites with and without MoS_2 filler were arrived at and average results are plotted as shown in Fig.6. Figure shows the linear increase in the hardness as the percentage of MoS_2 content increases, although the magnitude increase in hardness with MoS_2 filler content is not substantial.

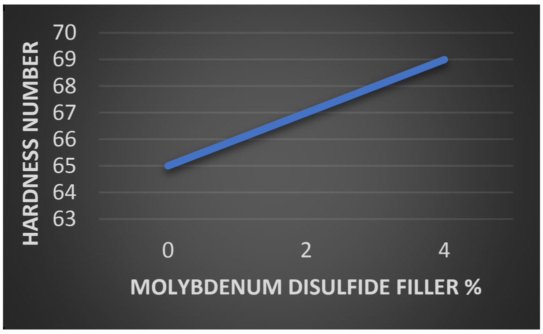

Figure 6. Hardness number as a function of Molybdenum disulfide filler content.

E. Three Body Abrasive Wear Tests

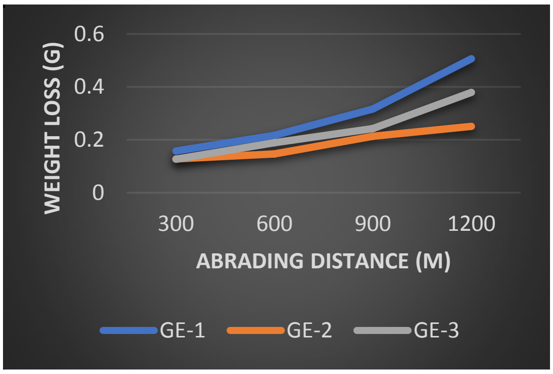

Figure 7. Weight loss Vs Abrading Distance

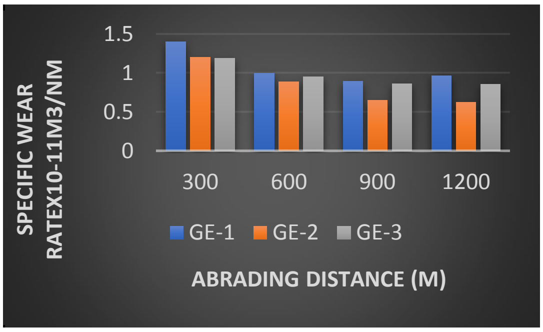

Figure 8. Specific Wear rate Vs Abrading Distance.

Fig. 7 show the weight loss in grams as a function of sliding distance for G-E composites with and without MoS_2 filler. It is observed that weight loss is increasing with increased abrading distance and amount of wear has been decreased with increase in MoS_2 filler content.

The addition of filler has altered the wear behaviour characteristics of composites and addition of filler has resulted in better wear resistance. From the graph it is clear that glass fiber reinforced epoxy composites with 2% MoS_2 filler showed the best wear behaviour than G-E composite without and with 4% MoS_2 filler.

Fig. 8 shows specific wear rate as a function of abrading distance for G-E composites with and without filler. These figures indicate that the specific wear rate generally dropped with increased abrading distance. G-E composite without filler showed maximum specific wear rate at an abrading distance of 300m, whereas G-E composite with 2% filler showed the least specific wear rate.

Also it can be observed that the specific wear rate for G-E composites without filler and with 4% filler didn't show any fixed trend of variation with increased abrading distance, whereas specific wear rate for G-E composite with 2% filler marginally decreased with increased abrading distance for all the loads suggesting that 2% MoS_2 filled G-E composite showed stable wear characteristics as compared to other two.

F. Air Jet Erosion Test

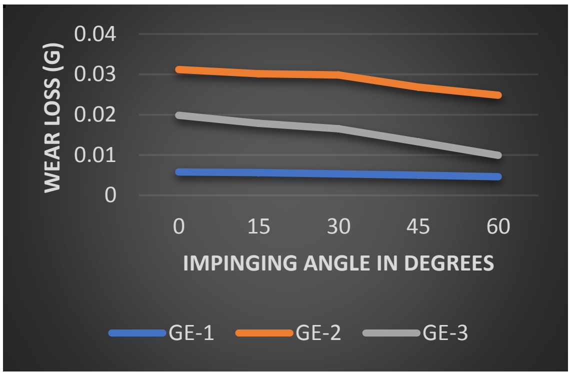

Figure 9. Weight loss Vs Impinging angle.

Fig. 9 shows the erosive wear loss as a function of impinging angle. It is observed that erosive wear decreased with increased impinging angle. G-E composite with 2%MoS_2 additive resulted in lesser erosive wear compared with the other two. Also no significant variation of wear loss was observed. This shows that this composite with 2% MoS_2 filler showed stable wear properties even under ageing conditions.

IV. ARTIFICAIL NEURAL NETWORK

Artificial neural network approach has been used in the current study. with the help of ANN, experimental result was validated, and results of ANN shows experimental results were matched with ANN results. For this Study MATLAB Latest licensed version was used.

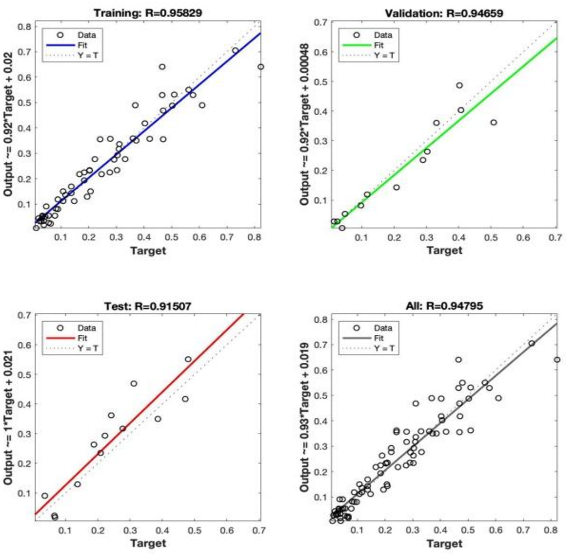

Figure 10. Regression plot for LM algorithm

Fig. 10 represent the regression graph using LM algorithm. From the graph, it is clear that, linear regression graph was obtained, and output tracks the target well for testing and validation and value of R=0.95.

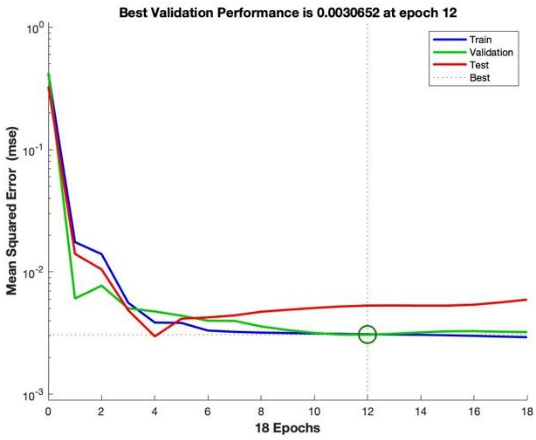

Figure 11. Performance plot for LM algorithm

Fig. 11 represents mean square error as a function of epochs. To test the performance, many datasets were used and best validation was obtained for 10th iteration. Also Fig. 12 represents the final output of ANN. From the figure it is very clear that, experimental results are almost matched with the predicted values.

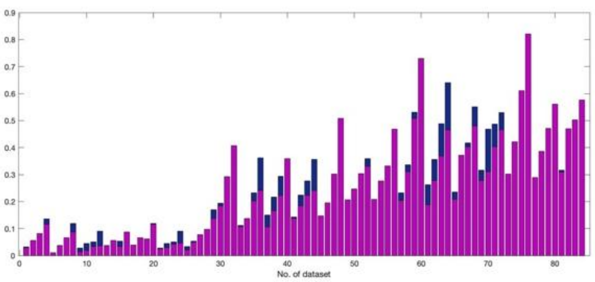

Figure 12. ANN validation

V. RESULTS

Glass fiber reinforced epoxy composite with 4% MoS_2 filler content showed the maximum tensile strength and elongation, whereas maximum flexural strength and modulus was obtained for G-E Composites with 2% MoS_2 filler. An increase in hardness was observed with increased percentage of MoS_2 filler in the composite.

Abrasive wear of glass fiber reinforced epoxy composite was strongly dependant on the test parameters such as load and sliding distance. Comparative wear performance of different composites showed increased weight loss and decreased specific wear rate with increased load and abrading distance. MoS_2 filler provided better abrasion resistance to composite as compared to unfilled ones. Also wear rate decreased with increased filler content. Best abrasive wear characteristics were obtained for the G-E composite with 2% MoS_2 filler.

Weight loss of G-E composite during abrasion test was strongly dependant on the test parameter namely impinging angle. Comparative erosive wear performance of all the composites showed that wear loss decreased with increased impinging angle. G-E composites with filler showed better erosion resistance. Best erosive wear performance was seen for G-E composite with 2% MoS_2 filler.

ANN validation was done using MATLAB software. From the study, experimental results were matched with the predicted values of ANN.

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