Investigationon Mechanical and Tribological Characterization of Nano Particulate Filled Fiber Reinforced Hybrid Composites for Automobile Applications

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Abstract: In this study the abrasive wear behaviour and mechanical behaviour of glass fibre reinforced epoxy (G-E) ,Nano Silicon dioxide filled with G-E (SiO2-G-E) and Nano Aluminium oxide filled with G-E (Al2O3-G-E) composites have been carried out by using a rubber wheel abrasion test (RWAT) , Pin-on-disc test , along with Tensile strength test, Impact strength test and hardness test. Samples of G-E with 0%, 5%, 10% and 15wt% content of SiO2 and Al2O3 were tested under different loads and abrading distances. Also, conventional weighing of specimen, determination of wear volume of the specimen, specific wear rate of the specimen, and examination of the worn surface morphological features by scanning electron microscopy (SEM) were done. The results showed varied responses under different abrading distance because of the inclusion of different wt% of SiO2 and Al2O3 filler loading. Further, the test results show that glass fabric reinforcement obviously improves the strength of epoxy and glass fabric- Al2O3 exhibits a synergistic effect on the wear resistance and reinforcing epoxy simultaneously. Further, it was also noticed that G-E composite wear is reduced to a greater extent by addition of the Nano fillers ofSiO2 and further more by Al2O3,selected mechanical properties such as hardness, tensile strength, and elongation at fracture were analysed for investigating wear property correlations.

IndexTerms **– Glass fabric reinforced epoxy composite, SiO2 filler, Al2O3 filler, Abrasive wear, wear mechanisms.**

I. INTRODUCTION

Glass fiber reinforced polymer matrix composites have been extensively used in various fields such as aerospace industries, automobiles, marine, and defence industries [1]. Their main advantages are good corrosion resistance, lightweight, dielectric characteristic, and better damping characteristics than metals. Fabric reinforced and particulate filled polymer composites have become attractive because of their wide spread applications and low cost. A possibility that the incorporation of both particles and fibers in polymer could provide a synergism in terms of improved properties and performance has not been adequately explored so far. However, some recent reports suggest that by incorporating filler particles into the matrix of fiber reinforced composites, synergistic effects may be achieved in the form of higher modulus and reduced material cost, yet accompanied with decreased strength and impact toughness [2].

One part of composite material for engineering applications may be represented by a thermosetting polymer matrix, e.g. an epoxy resin, which already covers alone some of the demanded properties. Diglycidyl of bisphenol A (DGEBA) type epoxy resin being the most widely matrix for innumerable applications, owing to its well-balanced chemical, adhesive, thermal and processing characteristics. However, the high coefficient of linear expansion, low thermal conductivity and limited mechanical properties of epoxies limit their use in mechanical and tribological applications. Recently many attempts were made to develop epoxy resin composites modified by fibers and fillers to improve the mechanical and tribological performance of the epoxy matrix [3-5]. Bahadur and Zheng [6], in their studies on short glass fiber (SGF) reinforced polyester by varying SGF up to 60 wt% described the effect of glass fiber on mechanical properties of the composites. Epoxy resins are superior to polyesters in resisting moisture and other environmental influences and offer lower shrinkage and better mechanical properties. However, the structural application of epoxy resin and its composites is usually limited owing to the relatively poor thermal stabilities and load carrying capacity. In order to enhance the wear resistance and thermal stability, many research studies have been carried out. One of these is the fiber reinforcement into the epoxy matrix. Different synthetic fibers and hard ceramic or metal particles have been tried as fillers in the epoxy matrix [7-9]. Kim et al. [10] reported that the damage could occur during the fabrication process, storage, service, transport, and maintenance. They are susceptible to mechanical damage when they are subjected to effects of tension, compression, and flexure, which can lead to interlayer delamination. The increase of external load favors the propagation of delamination through the interlayer leading to the catastrophic failure of the component. Another work reported by Unal and Mimaroglu [11] evaluated mechanical properties of Nylon-6 by incorporating one or a combination of more than one filler by varying the weight percent. They observed that the tensile strength and modulus of elasticity of Nylon- 6 composites increased with increase in filler weight percent. Osmani [12] evaluated the mechanical properties of alumina filled glass-epoxy (G-E)

composites and reported that tensile and shear strengths decreased with increase in alumina content and flexural strength and modulus increased. Suresha et al. [13] studied the mechanical and sliding wear behavior of SiC filled G-E composites and concluded that the SiC filler addition improved the mechanical as well as wear resistance of G-E composites. Wetzel et al. [14] evaluated the mechanical and tribological properties of epoxy filled with nano-Al_2O_3 and micro$CaSiO_3$ hybrid composites. They concluded that incorporation of micro-and nano-scale particles improved the mechanical as well as tribological properties.

Among the wear types, the abrasive wear situation encountered in industries connected with power, automobile, pumps handling industrial fluids, and earth moving equipment has been received increasing attention. Glass/carbon fibers are the best known and most widely used reinforcing fibers in advanced polymeric composites. Reports related to application of polymer matrix composites on mechanical and tribological components such as gears, cams, wheels, and impellers are cited in literature. The importance of the tribological properties convinced various researchers to study the wear behavior and to improve the wear resistance of polymers and fiber-reinforced polymeric composites. Chand et al. [15] reported the three-body abrasive wear behavior of short glass fiber reinforced polyester composite. Chand and Gautam [16] reported the influence of load on the abrasion of fly ash, glass fiber- reinforced composites. Suresha et al. [17-19] investigated the abrasive wear behavior of epoxy/vinyl ester filled with or without particulate filler and glass/carbon fabrics. An investigation on the wear behavior of the composite materials with epoxy matrix filled with hard powders was reported by Visconti et al. [20]. Studies were also made on the effect of various fillers on the abrasive wear behavior of polymeric materials [21] and polymer composites [22-24].

A survey of the literature indicates that the effect of fiber/filler on the abrasion of polymer/composites is a complex and unpredictable phenomenon [25]. This is because physical effects such as fiber fragmentation, debonding, pullout, etc., affect the behavior of composite material subject to the abrasive wear process. It is also difficult to predict their relative contribution because various other mechanisms and influencing factors are involved (ploughing, cutting and cracking of the matrix). Although, a good amount of work has been reported on mechanical and three-body wear behavior of polymer matrix composites as discussed earlier in this section, no literature could be cited on the mechanical and abrasive wear aspect of G-E filled with Al_2O_3 particles. For sliding elements under tribological loading, however, the industrial acceptability of polymers is often limited by their thermal behaviors. The degradation of their mechanical properties at elevated temperature restricts the possibility to apply of these materials at high sliding speed and loading conditions. That is why high temperature resistant polymers are generally preferred for such tribological applications. Therefore an attempt has, therefore, been made to study the three-body abrasive wear behavior of G-E composite filled with different proportions of very fine Al_2O_3 particles (particle size $\leq$5 µm) under two different loads and for different abrading distances (250-1000 m). The abrasive wear behavior has been quantified in terms of wear volume and specific wear rate. The different wear mechanisms under different abrasive wear conditions have also been reported.

II. Experimental Details

A. Materials and preparation method

The matrix material selected is an epoxy resin and woven glass plain weave fabrics made of glass fibers are used as the reinforcing material in all composites. Woven glass plain weave fabrics made of 360 g/meter square containing glass fibers of diameter of about 12 µm is employed. The epoxy resin (LAPOX L-12) is mixed with the hardener (K-6, supplied by ATUL India Ltd., Gujarat, India) in the ratio 100: l2 by weight. The average particle size of Silica and Alumina particles are in Nano meter. As regards to the processing, on a Teflon sheet, E-glass woven fabric are placed over which the epoxy matrix system consisting of epoxy and hardener was smeared. Dry hand lay-up technique is employed to fabricate the composites as represented in fig 1. The stacking procedure consists of placing the fabric one above the other with the resin mix well spread between the fabrics.

A porous Teflon film is used multiple times to complete the stack. To ensure uniform thickness of the sample, a 3 mm spacer is used. The mould plates are coated with release agent in order to aid the ease of separation on curing.The sheets of fiberglass are placed over the mold and rolled down into the mold using steel rollers. The material must be securely attached to the mold; air must not be trapped in between the fiberglass and the mold. Additional resin is applied and additional sheets of fiberglass. Rollers are used to make sure the resin is between all the layers, the glass is wetted throughout the entire thickness of the laminate, and any air pockets are removed. The work must be done quickly enough to complete the job before the resin starts to cure. Laminates are left to cure under standard atmospheric conditions. The cast of each composite after 12 h of impregnation and dried for 2 h at 80°C followed by compression moulding at a temperature of 100° C & pressure of 7.35 MPa. The slabs so prepared measured 250 mm x 250 mm x 3 mm by size. To prepare different wt. % of Silica and Alumina filled G-E composites, besides the epoxy hardener mixture, additional wt. % of Silica and Alumina particles were included to form the resin mix.

The details of the composites (including wt% of the constituents) prepared are shown in Table 1. The mechanical and abrasion test samples were prepared according to ASTM standards from the cured slabs filled with Silicon dioxide filled G-E (SiO2-G-E) and Aluminium oxide G-E (Al2O3-G-E) using abrasive cut-off machine.

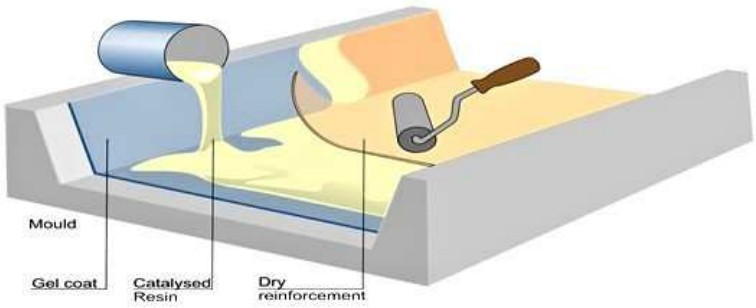


Fig 1: Hand lay-up technique.

Table 1: Composite Prepared For Present Work

Composites	Compositions
C1	Glass Fiber (55wt %) + Epoxy (45wt %)
C2	Glass Fiber (55wt %) + Epoxy (40wt %) + Nano Silicon dioxide (5 wt %)
C3	Glass Fiber (55wt %) + Epoxy (35wt %) + Nano Silicon dioxide (10wt %)
C4	Glass Fiber (55wt %) + Epoxy (30wt %) + Nano Silicon dioxide (15wt %)
C5	Glass Fiber (55wt %) + Epoxy (40wt %) + Nano Aluminum oxide (5 wt %)
C6	Glass Fiber (55wt %) + Epoxy (35wt %) + Nano Aluminum oxide (10wt %)
C7	Glass Fiber (55wt %) + Epoxy (30wt %) + Nano Aluminum oxide (15wt %)

B. Characterization

Density of the composites was determined by using a high precision electronic balance (Mettler Toledo, Model AX 205) using Archimedes principle. Hardness (Shore-D) of the samples was measured as per ASTM D2240, by using a Hiroshima make hardness tester (Durometer). Three readings at different locations were noted and average value is reported. Tensile properties were measured using a computerized Universal testing machine in accordance with the ASTM D-3039 procedure at a cross head speed of 1 mm/min and a gauge length of 70 mm. The tensile strength and modulus were determined from the stress-strain curves. Two samples were tested in each set and the average value was reported. The tensile tests were carried out on a fully automated Kalpak Universal testing machine connected to a computer with DAPMAT software.

The three-body abrasive wear tests (Rubber Wheel Abrasive Test) were conducted using a dry sand/rubber wheel abrasion tester as per ASTM G-65. The details of the samples preparation and wear testing procedure have been described elsewhere [17].

The experiments were carried out at three different abrading distances (150, 300 and 450 m) under constant load (30 N). Densities of the composites were determined using a high precision weighing balance by using Archimedes' principle. The wear was measured by the loss in weight, which was then converted into wear volume using the measured density data. After the wear test, the sample was again cleaned. The specific wear rate (*Ks*) was calculated from the equation:

$$\text{Specific wear rate} = (\text{Wear volume}) / (\text{Load x Abrading distance}) \text{ in } m^3/Nm$$

III. Results and Discussion

3.1 Effect of Filler Loading on Hardness

By using Duro-hardness tester, the Shore-D hardness of the composites is measured; the values recorded are given in Table 2. The hardness of G-E composite increased with increase of SiO2 and Al_2O_3 filler loading. From Table 2, we can see that the SiO2 and Al_2O_3 filler greatly increased the hardness of G-E, which can be attributed to the higher hardness and more uniform dispersion of SiO2 and Al_2O_3 filler. The higher hardness is exhibited by the 15 wt% Al_2O_3 filled G-E compared to other Nanocomposites. The table shows that for a 15 wt% increase in Al_2O_3 content there is 12% increase in hardness. The increase in Al_2O_3 content results in an increase in brittleness of the composite. Hence this results in an increase in hardness value of the composite. Particulate filled G-E composites with sufficient surface hardness is resistant to in-service scratches that can compromise the fatigue strength and lead to premature failure. Therefore, under an indentation loading, particles would undergo elastic rather than plastic deformation, as compared to unfilled G-E composites.

Table 2: Hardness of the materials

Materials	G+E	G+E+ 5%SiO_2	G+E+ 10%SiO_2	G+E+ 15%SiO_2	G+E+ 5%Al_2O_3	G+E+ 10%Al_2O_3	G+E+ 15%Al_2O_3
Hardness	63	65	70	74	66	72	75

3.2 Abrasive Wear Volume and Specific Wear Rate

A. Three Body Abrasion Test:

Dry sand rubber wheel abrasion test is one of the most widely used abrasion testing method. The abrasive, for example dry sand, is fed between the specimen and the rotating rubber wheel. Other abrasives can be used depending on the application such as, industrial equipment for grinding grain, paints, plastics, coatings, slurry abrasion, construction and automobile equipment.
The test specimen is fitted as shown in Fig 2

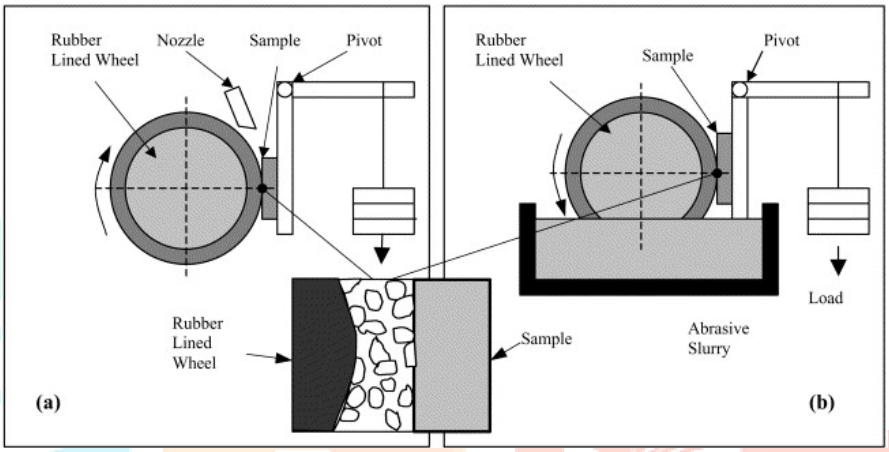
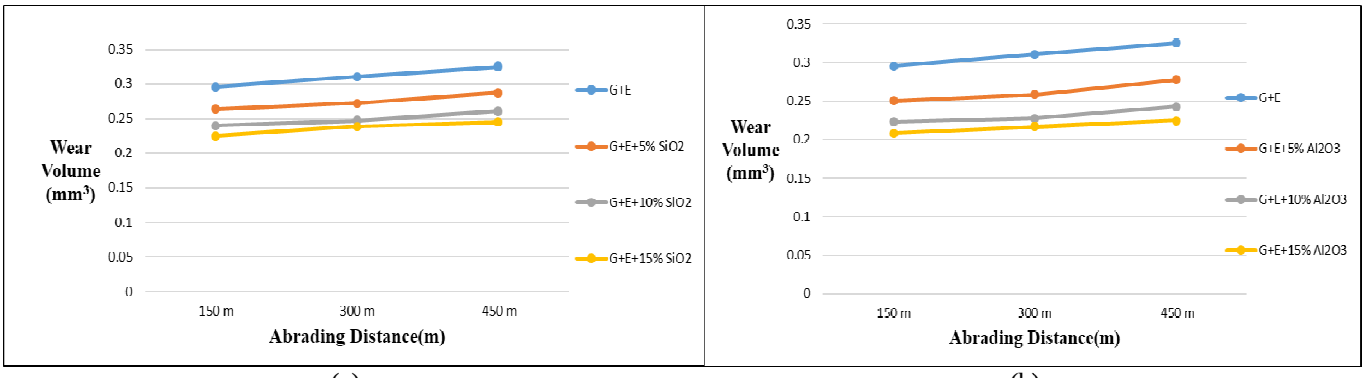


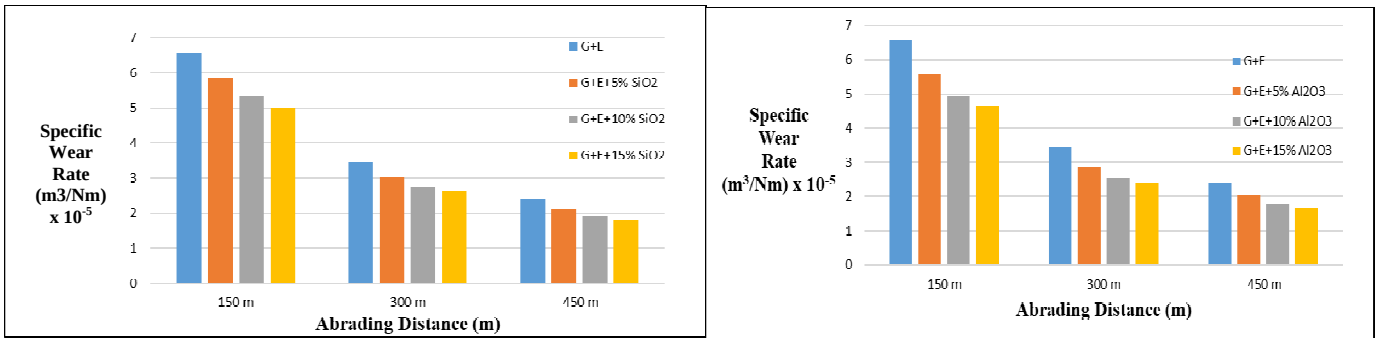
Fig 2: Schematic Representation of Rubber Wheel Abrasion Test

The specimen gets hit by the rotating rubber wheel and sand. The sand is sandwiched between the specimen and the rubber wheel. The frictional force due to the load and the speed along with the distance of abrasion will affect the wear of the specimen. We can observe that the wear is high for the G-E specimen compared to that of the SiO2 material filled specimen, and SiO2 wear is greater compared to that of Al2O3.
Figure 3a (SiO2 filler specimen) and 3b(Al2O3 filler specimen) show the wear volume loss with load for different abrading distances. It is evident from these figures that irrespective of the type of samples used, there is a linear trend of wear volume loss. The Al_2O_3 filled G- E composite exhibited considerably lower wear volume loss than that of SiO2 and G-E composite. This is attributed to the glass fiber reinforcement in epoxy decrease the abrasive wear resistance due to debonding and tearing at the glass/matrix interface.
Figure 4a and b shown as histograms for specific wear rate of the specimens, the comparative abrasive wear performance of G-E,SiO2and Al_2O_3-G-E composites at 150m, 300m and 450m distance respectively. The specific wear rate data reveals that initially the specific wear rate tends to decrease with increasing abrading distance and further it strongly depends on the applied load for both samples. Also observed is the earlier noted fact that G-E composite exhibits the highest specific wear rate. We can observe that for Al_2O_3-G-E system, the specific wear rate is on the lower side.



(a) (b)

Fig 3: Wear Volume Loss of Unfilled, SiO2 & Al2O3 Filled G-E Composites



(a) (b)

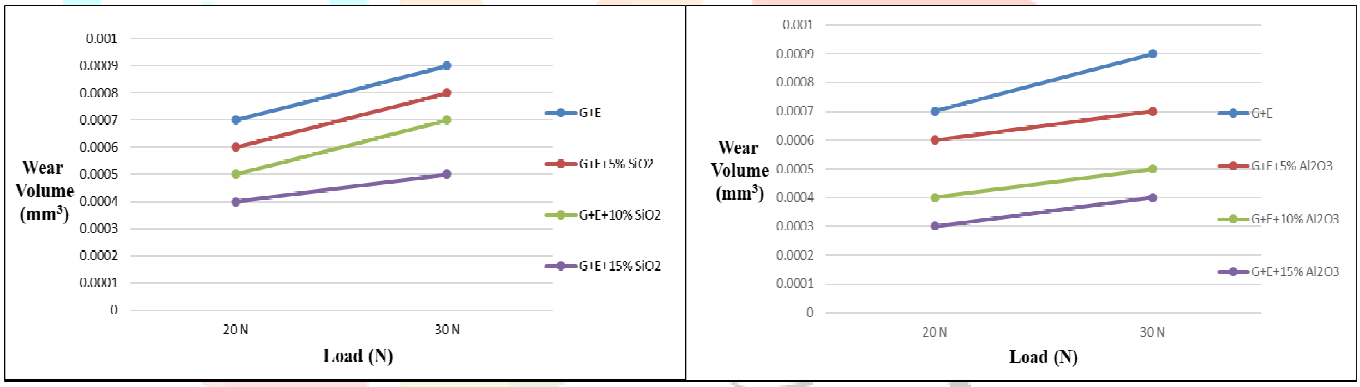
Fig 4: Specific Wear Rate of Unfilled, SiO2 and Al2O3 Filled G-E Composites

B. Two Body Abrasion Test

The standard equipment used to determine the wear resistance of surfaces is the pin on disc tester. The pin on disc machine is versatile unit designed to evaluate the wear and friction characteristics on a variety of materials exposed to sliding contacts in dry or lubricated environments. The sliding friction test occurs between stationary pin stylus and a rotating disk. Normal load, rotational speed, and wear track diameter can be varied. Electronic sensors monitor wear and the tangential force of friction as a function of load, speed, lubrication, or environmental condition.

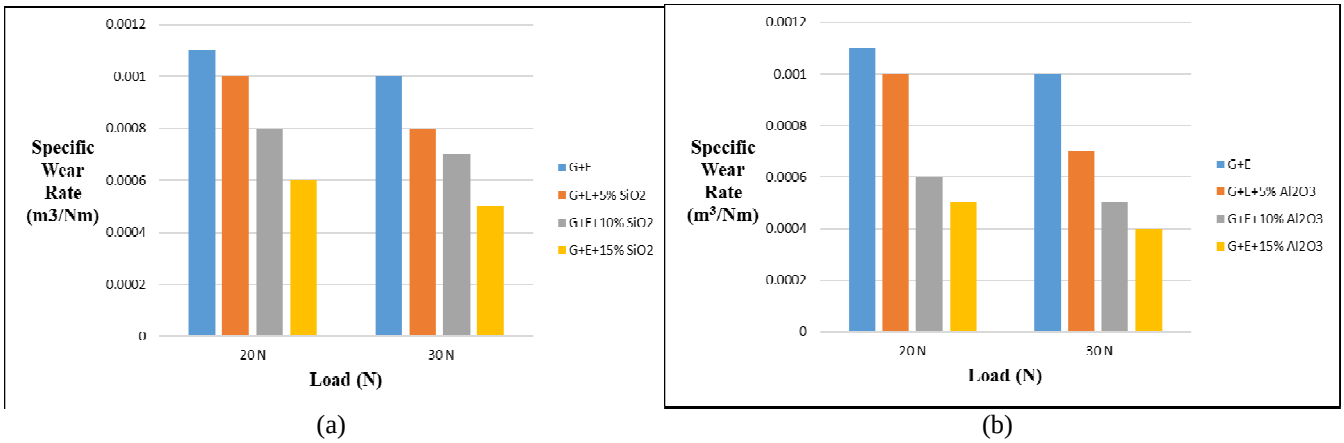
The specimen was tested for constant abrading distance and varying loads i.e. for 20N and 30N loads. Here also we can see the effect of fillers acting on the wear of the materials.

From Figure5 (a), (b) i.e. wear volume vs load and Figure 6 (c), (d) i.e. specific wear rate vs load, we can conclude that that for constant sliding distance under various loads the wear volume and specific wear rate of Nano Aluminum oxide filled glass epoxy composites are lower compared to glass epoxy with and without Nano Silicon dioxide. Therefore, the addition of fillers plays an important role in decreasing the wear of the composites.



(a) (b)

Fig 5: Wear Volume Loss of Unfilled, SiO2 & Al2O3 Filled G-E Composites

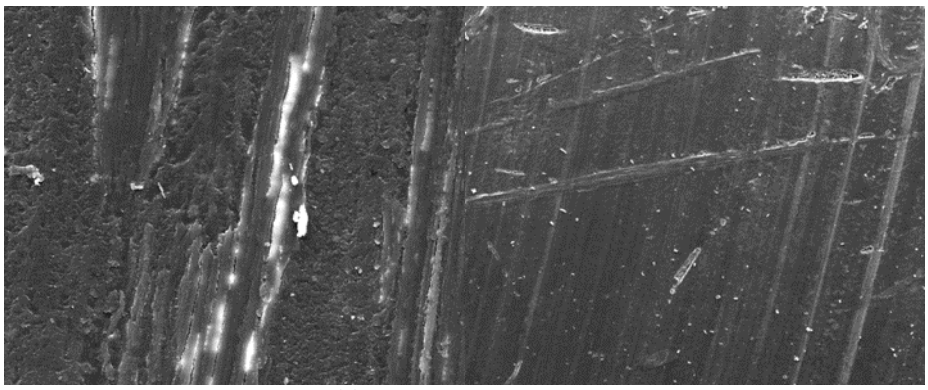


(a) (b)

Fig 6: Specific Wear Rate of Unfilled, SiO2 and Al2O3 Filled G-E Composites

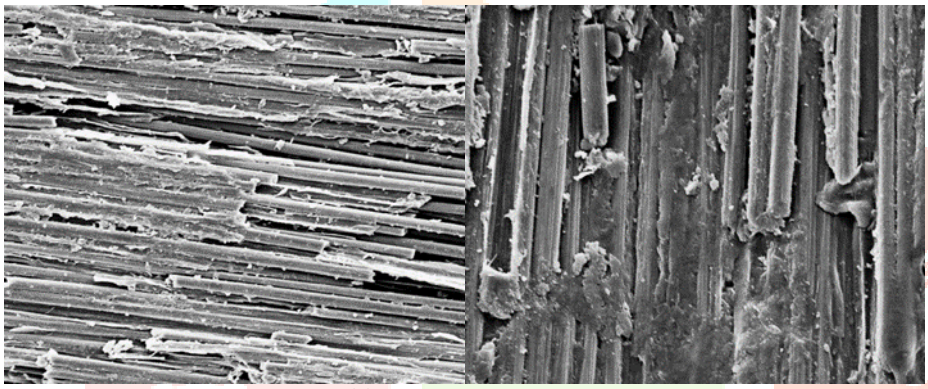
3.3 Worn surface analysis

Worn surfaces of the materials were examined by SEM to find out the wear mechanisms. Abrasive wear occurs by three different wear mechanisms, i.e. micro ploughing, micro cutting and micro cracking. SEM photographs of abraded surfaces are given below in Figure 7



(a) (b)

Fig 7: (a) and (b) Wear Mechanism Under Two body abrasion test(Pin on Disc Test)



(c) (d)

Fig 7: (c) and (d) Wear Mechanism Under Rubber Wheel Abrasion Test

IV. CONCLUSION

The experimental investigations of tribological properties of Silicon dioxide (SiO2) filled and Aluminum oxide (Al2O3) filled glass epoxy composites leads to the following conclusions.

1. This work shows that successful fabrication of a Glass fiber reinforced epoxy composites filled with Silicon carbide and Silicon dioxide is possible by simple hand lay-up technique.
2. It is noticed that there is a significant improvement in the tribolgical properties like Wear with addition of Silicon dioxide and Aluminum oxide fillers in the glass epoxy composites.
3. The wear volume of unfilled glass epoxy blend as compared to that of Silicon dioxide and Aluminium oxide filled glass epoxy blend is high.
4. The specific wear rate is also low for the Silicon dioxide and Aluminium oxide filled glass epoxy when compared to the unfilled glass epoxy composites.
5. SEM studies of worn surfaces support the involved mechanisms and indicate damage to the matrix and filler as well as debonding of matrix and fillers of Aluminium Oxide and Silicon Dioxide filled glass epoxy composites.

V. REFERENCES

1. Kuljanin, J., Vuckovic, M.,.Comor,M.I., Bibic, N., Djokovic, V., Nedeljkovic, J.M., Influence of CdS-filler on the thermal properties of polystyrene, European Polymer Journal,2002, 38(8), pp 1659–1662 .
2. Weidenfeller, B., Hofer, M., Schilling, F., Thermal conductivity, thermal diffusivity, and specific heat capacity of particle filled polypropylene, Composites Part A: Applied Science and Manufacturing, 2004, 35 (4), pp 423–429.
3. Ferreira, J.M., Pires, J.T.B., Costa, J.D., Zhang, Z.Y., Errajha ,O.A., and Richardson, M., Fatigue Damage Analysis of Aluminized Glass Fiber Composites, Materials Science and Engineering A, 2005, 407, pp 1–6

4. Amuzu, J.K.A., Briscoe, B.J.and Tabor, D., Polymers as Bearing and Lubricants; Aspects and Fundamental Research: Advances in Tribology, 1978, pp 59-62.
5. Kaushal ,S.,and Kishore, Analysis of Deformation Behaviour and Fracture Features in Glass-epoxy Composites Toughened by Rubber and Carbon Additions, Journal of Materials Science Letters, 1992, 11, pp 86–88.
6. Bahadur, S.,andZheng, Y., Mechanical and Tribological Behaviour of Polyester Reinforced with Short Glass Fibers, Wear, 1990,137, pp 251-266.
7. Zhang, Y., Pickels, C.A., and Cameron, J., The Production and Mechanical Properties of Silicon Carbide and Alumina Whisker-Reinforced Epoxy Composites, Journal of Reinforced Plastics and Composites, 1992, 11, pp 1176–1186.
8. Cao, Y.,and Cameron, J. ,Flexural and Shear Properties of Silica Particle Modified Glass Fiber Reinforced Epoxy Composite, Journal of Reinforced Plastics and Composites, 2006, 25, pp 347–359.
9. Srivastava, V.K., Pathak, J.P., and Tahzibi, K.,Wear and Friction Characteristics of Mica-filled Fiber Reinforced Epoxy Resin Composites, Wear, 1992,152, pp 343–350.
10. D-H kim Composite structures for civil and architectural engineering.
11. unal ,H., and mimargolu, A., Influence of filler addition on the mechanical properties of nylon-6 polymer, journal of reinforced plastics and composites, 2004, 23, pp 5461-69.
12. Osmani, Mechanical Properties of Glass-Fiber Reinforced Epoxy Composites Filled with Al2O3 Particles. Journal of Reinforced Plastics and Composites, 28, 2861-2867 (2009).
13. Suresha, B., Siddharamaiah, Kishore, Seetharamu, S., Sampathkumaran, P., Investigations on the influence of graphite filler on dry sliding wear and abrasive wear behaviour of carbon fabric reinforced epoxy composites, Wear, 2009, pp 267
14. Wetzel, B., Haupert, F., Zhang, M.Q., Epoxy nanocomposites with high mechanical and tribological performance, Composite Science and Technology, 2003, 63, pp 2055-2067.
15. Chand, N., Naik, A.M, and Neogi, S., Three-Body Abrasive Wear of Short Glass Fiber Polyester Composite, Wear, 2000, 242(1-2), pp 38-46.
16. Chand N., and Gautam, K.K.S., Influence of Load on Abrasion of Fly Ash-glass Fiber reinforced Composites, Journal of Materials Science Letters, 1994, 13(4), pp 227-300.
17. Suresha, B., Chandramohan, G., Siddaramaiah, Sampathkumaran, P. , and Seetharamu, S., Three-Body Abrasive Wear Behavior of Carbon and Glass Fiber Reinforced Epoxy Composites, Mater. Sci. Eng. A, 2007, 443(1-2), pp 285-292.
18. Suresha, B., and Chandramohan, G., Three-Body Abrasive Wear Behavior of Particulate- Filled Glass-Vinyl Ester Composites, J. Mater. Process. Tech., 2008, 200(1), pp 306-311.
19. Suresha, B., Chandramohan, G., Kishore, Sampathkumaran, P., and Seetharamu, S., Mechanical and Three-Body Abrasive Wear Behavior of SiC Filled Glass-Epoxy Composites, Polym. Compos., 2008, 29(9), pp 1020-1025 .
20. Visconti, I.C. ,Langella, A., and Durante, M., The Wear Behaviour of Composite Materials with Epoxy Matrix Filled with Hard Powder, Applied Composite Materials, 2001, 8(3), pp 179-189.
21. Vaziri, M., Spurr , R.T., and Stott, F.H., An Investigation of the Wear of Polymeric Materials, Wear, 1988, 122(3), pp 329-342.
22. Vishwanath, B., Verma A.P. , and Rao, C.V.S.K., Wear Study of Glass Woven Roving Composite, Wear, 1989, 131(2), pp 197-205.
23. Suresha, B., Chandramohan, G., Siddaramaiah and Jayaraju, T., Three-body Abrasive Wear Behavior of E-glass Fabric Reinforced/Graphite-filled Epoxy Composites, Polymer Composites, 2008, 29(6), pp 631-637.
24. Suresha, B., Chandramohan ,G.andMohanram, P.V. , Role of fillers on three-body abrasive wear behavior of glass fabric reinforced epoxy composites, Polymer Composites, 2009, Vol. 30(8), pp. 1106-1113.
25. Bartenov ,G.M., and Lavrentov, V.V. , Lee L.H., and Ludema, K.C., Friction and Wear of Polymers, Tribology Series 6, Elsevier, Amsterdam ,1981.
26. JayshreeBijwe, John Rajesh, J., Jeyakumar, A., Gosh A., and. Tewari, U.S , Tribology International, 2000, 33, 6971.