INVESTIGATIONS ON THREE-BODY ABRASIVE WEAR BEHAVIOUR OF SILICON CARBIDE AND GRAPHITE FILLED GLASS-VINYL ESTER COMPOSITES

B Suresha[1*], G Chandramohan[2], Siddaramaiah[3*,4] and Joong-Hee Lee[4]

[1]Department of Mechanical Engineering, National Institute of Engineering, Mysore-570 008, India
[2]Department of Mechanical Engineering, PSG College of Technology, Coimbatore-641 004, India
[3]Department of Polymer Science and Technology, Sri Jayachamarajendra College of Engineering, Mysore -570 006, India
[4]Bin Fusion Research Team, Department of Polymer & Nano Science and Technology, Chonbuk National University, Jeonju, Jeonbuk, 561-756, South Korea

Abstract

The effect of silicon carbide (SiC) and graphite fillers incorporation on the abrasive wear behaviour of glass-vinyl ester (G-V) composites have been investigated. The three-body abrasive wear behaviour was assessed by rubber wheel abrasion tests (RWAT). The worn surfaces were examined using scanning electron microscopy (SEM). The addition of SiC and graphite fillers in G-V composite improves the abrasion resistance under different loads/abrading distances. The SEM studies indicate the reasons for failure of composites and influencing parameters.

Keywords: Three-body abrasive wear, Fillers, Glass-vinyl ester composite, Morphology of worn surfaces.

1.0 INTRODUCTION

Polymers and their composites form a very important class of tribo-engineering materials and are invariably used in mechanical components such as gears, cams, bearings, bushes, bearing cages etc., where wear performance in non-lubricated condition is a key parameter for the material selection [1]. Polymer composites are subjected to abrasive wear in many applications [2]. Three-body abrasive wear is often of considerable practical importance, for example in coal handling equipments in power plants, gear pumps handling industrial fluids and agricultural machine components, but appears to have received much less attention than a two-body abrasion. Very little has been reported on the effect of fiber/filler reinforcement on three-body abrasive wear behaviour of polymer composites [3]. In recent years, much research has been devoted to exploring the potential advantage of thermoset matrix for composite applications [4]. One such matrix is vinyl ester, which has found a place in the family comprising the thermoset engineering polymers due to its excellent mechanical properties with good chemical/corrosion resistance. Vinyl ester resins are stronger than polyester resins and cheaper than epoxy resins. Vinyl ester resins utilize a polyester resin type of cross-linking molecules in the bonding process. Vinyl ester is a hybrid form of polyester resin which has been toughened with epoxy molecules

within the main molecular structure. A notable advance in the polymer industry has been the use of fiber and particulate fillers as reinforcements in polymer matrix. Particulate fillers are of considerable interest, not only from an economic view point, but as modifiers especially the physical properties of the polymer. Furthermore, it is known that the shape, size and volume fraction of any filler will influence this modifying effect on the properties [5]. In view of the above, this research article, reports a study of three-body abrasive wear performance of particulate filled glass-vinyl ester (G-V) composites.

2.0 EXPERIMENTAL DETAILS

2.1 Experimental materials and manufacturing method

Woven E-glass fabric (density 2.54 g/cc and modulus 72.4 GPa) having fibers of diameter 8-12 μm were used as a reinforcing material in vinyl ester composites. The resin, a Bakellite Hylane product of grade HPR 8171 having density 1.21 g/cc and modulus 2.6-4.0 MPa was used as the matrix. Methyl ethyl ketone peroxide (MEKP), cobalt naphthanate and N,N'-dimethyl aniline were used as catalyst, accelerator and promoter respectively. The average particle size of graphite and SiC fillers are 60 and 25μm and their corresponding density values are 1.8 and 3.1 g/cc respectively. Filler were procured from the local market.

As regards the processing, on a teflon sheet E-glass woven roving fabric, was placed, over which the vinyl ester matrix system consisting of vinyl ester, cobalt naphthanate accelerator and MEKP catalyst in the weight ratio of 1:0.015:0.015 was smeared. Dry hand lay up technique was employed to fabricate the composites. 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 was again used to complete the stack. To ensure uniform thickness of the sample, a 3 mm spacer was used. The mould plates were coated with release agent in order to aid the ease of separation on curing. The whole assembly was kept in a hydraulic press at a pressure of 0.5 MPa and allowed to cure for a day at room temperature. The slabs so prepared measured 250 mm X 250 mm X 3 mm by size. To prepare SiC/graphite and SiC particulate filled G-V composites, besides the vinyl ester hardener mixture additional 5 % filler particles by wt were included to form the resin mix. The details of the composites (including wt percent of the constituents) made are shown in Table 1. The weight percent of glass fibers in the woven glass fabric vinyl ester composites determined is about 48 ± 2 %. Abrasion test samples of size 75 mm x 25 mm x 6 mm were prepared from the cured sheet using abrasive cut-off machine.

Table 1. Formulations of E-glass fiber reinforced vinyl ester composites with sample codes

Sample Code	Vinyl ester content (wt. %)	Filler (wt. %)
G-V	50±2	0.0
SiC-G-V	45±2	5.0 (SiC)
Gr-SiC-G-V	45±2	2.5+2.5 (Gr+SiC)

2.2 Abrasive wear test

In the present study silica sand (density 2.6 g/cm^3 and Knoop hardness 875) was used as the abrasive. The abrasive particles of AFS 60 grade silica sand were angular in shape with sharp edges. The abrasive was fed at the contacting face between the rotating rubber wheel and the test sample. The tests were conducted at a rotational speed of 200 rpm. The rate of feeding the abrasive was 255 ± 5 g/min. The sample was cleaned (dry) and its initial weight was determined in a high precision digital balance (0.1 mg accuracy, Mettler, TOLEDO) before it was mounted in the sample holder. The abrasives were introduced between the test specimen and rotating abrasive wheel composed of chlorobutyl rubber tyre (hardness: Durometer-A 58-62). The test specimen was pressed against the rotating wheel at a specified force by means of lever arm while a controlled flow of abrasives abrades the test surface. The rotation of the abrasive wheel was such that its contacting face moves in the direction of sand flow. The pivot axis of the lever arm lies within a plane, which is approximately tangent to the rubber wheel surface and normal to the horizontal diameter along which the load is applied. At the end of a set test duration, the specimen was removed, thoroughly cleaned and again weighed (final weight). The difference in weight before and after abrasion was determined. At least three tests were performed and the average values so obtained were used in this study. The experiments were carried out at two different loads (22 N and 32 N) at a constant sliding velocity of 2.15 m/s. Further the abrading distances were varied in steps of 270 m from 270 m-1080 m. The wear was measured by the loss in weight, which was then converted into wear volume using the measured density data. The specific wear rate (K_s) was calculated from the equation;

$$K_S = \frac{\Delta V}{L \times d}\ m^3 / Nm \qquad (1)$$

where, 'ΔV' is the volume loss in m^3; 'L' is the load in Newtons and 'd' is the sliding distance in metres.

2.3 Microscopy

After wear test, the worn surfaces were examined using a scanning electron microscope (JSM 840A model and JEOL make). Before the examinations, a thin gold film was deposited on the worn surface.

3.0 RESULTS AND DISCUSSION

3.1 Abrasive wear volume and specific wear rate

Figures 1 (a)-(b) shows the wear loss in volume of the composite specimens at 22 and 32 N loads respectively. It is clear from these figures that for all the polymer composites used in this study there is a near linear wear volume loss with abrading distance. It indicates a steady-state wear with a constant wear rate. The highest wear volume is for unfilled G-V and the lowest is for SiC-filled G-V composites. For SiC filled G-V and Gr-SiC filled G-V composites there is an average increase in abrasion resistance of 33 % and 12 % as compared to unfilled G-V composites.

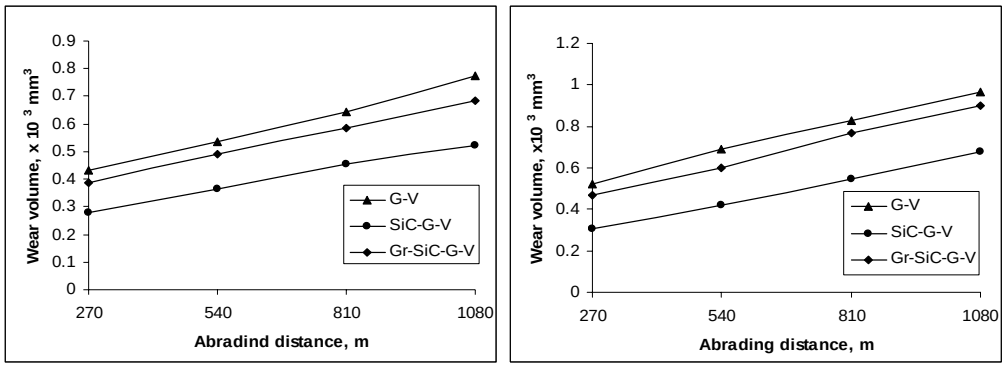

Figure 1. *Wear volume as a function of abrading distance at (a) 22 N load and (b) 32 N load (200 rpm speed).*

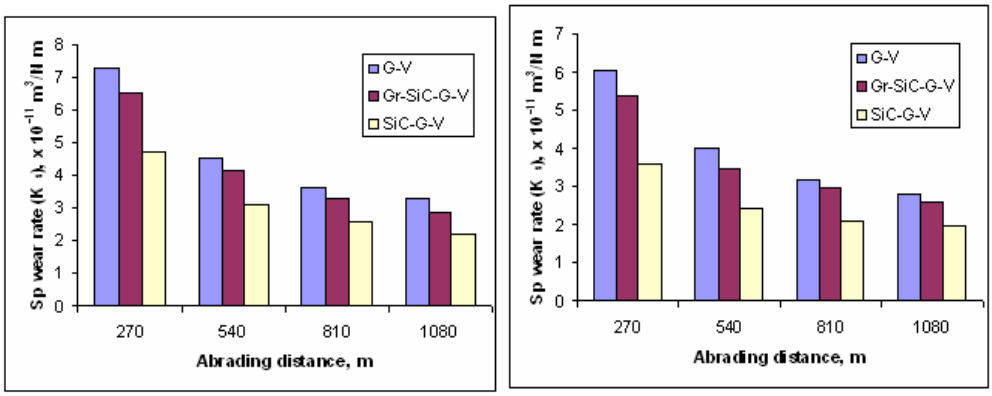

Figure 2. *Specific wear rate as a function of abrading distance (a) 22 N load and (b) 32 N load (200 rpm speed).*

The variation of specific wear rate in G-V, Gr-SiC-G-V and SiC-G-V composites is shown in Figures 2(a)-(b). At all abrading distances, the highest specific wear rate is for the unfilled G-V and the lowest for SiC-filled G-V composites was noticed. For all composites of this study, the specific wear rate drops with increase in abrading distance. The influence of fibers and/or fillers on the abrasive wear resistance of neat polymer is more complex and unpredictable and mixed trends are reported [6]. Similar Sole et al [6] have made the similar observations for PP composites.

3.2 Morphology of abraded surfaces

To correlate the wear data better, SEM photographs presented in Figures 3(a)-(b) to 5(a)-(b) pertaining to a load of 32 N and at different abrading distances for G-V, Gr-SiC-G-V and SiC-G-V composites are considered. Figure 3(a)-(b) shows the abrasive wear surfaces of unfilled G-V composite at a load of 32 N, 270 and 1080 m abrading distance respectively. The deep furrows in the abrading direction due to the ploughing action by sharp abrasive particles are seen on the surface. SEM images (Figure 3(b)) depicts severe damage to the matrix, more fiber breakage and some fibers are pulled-out from the surface. In this figure the brittle fracture of the material due to the cutting action by the abrasive particles are apparent and the extent of damage to the matrix and fiber is severe compared to lower abrading distance (Figure 3(a)).

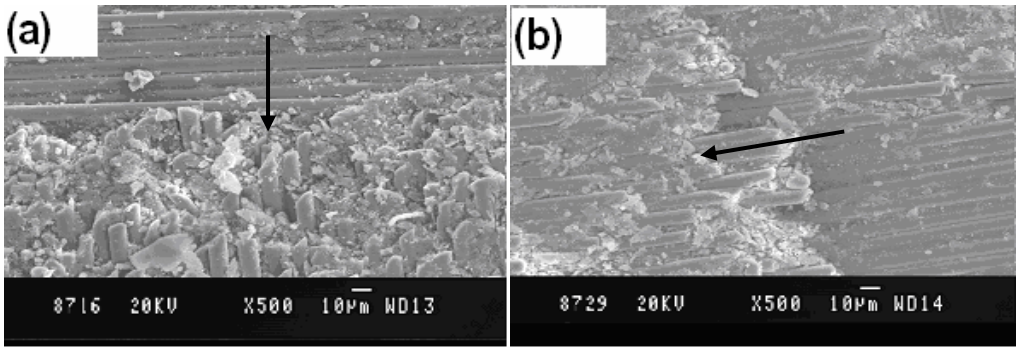

Figure 3. *SEM images of the unfilled glass fibre reinforced vinyl ester composite after abrasion at (a) 270 m, 32 load and (b) 1080 m, 32 N load.*

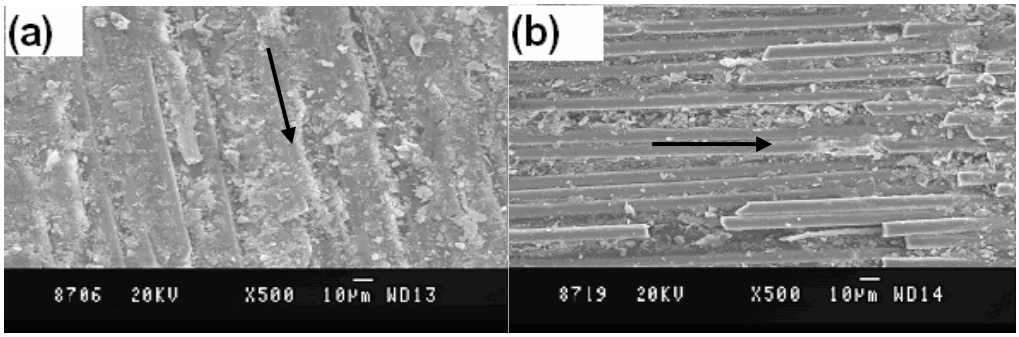

Figure 4. *Electron photomicrographs of the SiC filled glass fibre reinforced vinyl ester composite after abrasion at (a) 270 m, 32 load and (b) 1080 m, 32 N load.*

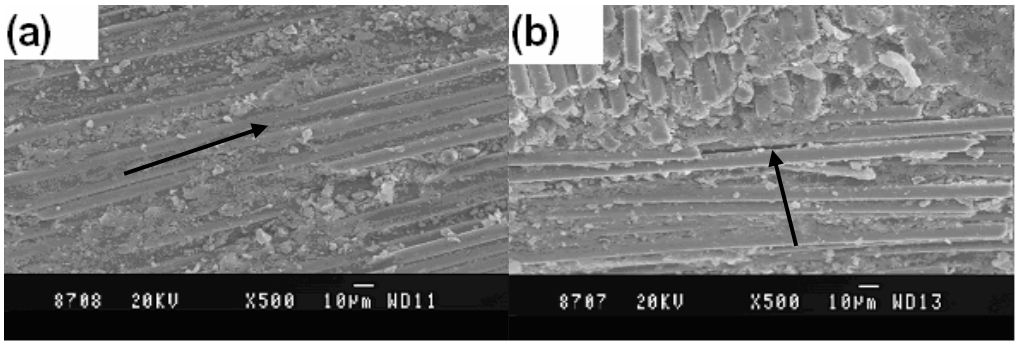

Figure 5. *Electron photomicrographs of the graphite and SiC filled glass fibre reinforced vinyl ester composites after abrasion at (a) 270 m, 32 load and (b) 1080 m, 32 N load.*

Figures 4(a) - (b) shows the pattern of abrasion wear in SiC-filled G-V composites. The SiC-filled G-V system shows less of matrix phase wear out in Figure 4(a). The protrusion of the phase and resultant less wear out are seen in Figure 4(b). In SiC-filled G-V composites, as it contains a combination of hard and soft phases, severity and extent of damage on the specimen surface becomes less, in the softer regions as noticed owing to the presence of hard SiC particles. As the hard phases/regions offer resistance to the damaging action of the abrasive, less of the damage is noticed in these systems. The spread of the matrix is distinctly seen in Figure 4(b). The SEM pictures amply demonstrate greater occurrence of debris that includes broken fibers when G-V system only are subjected to wear. Thus this observation lends credence to

the contention that the presence of SiC particles allow less of matrix wear during abrasion which in turn leads to lower fiber breakage.

SEM picture of graphite-SiC-filled G-V composite (Figure 5(a)) clearly show wear of matrix on the surface along the direction of the flow of abrasives. In Figure 5(b), long cracks in matrix and fiber cutting are seen, predominantly along the wear direction. Evidence of fiber breakage, few graphite particles and voids left by debonded fibers are observed. It is thought that the observed fiber damage is the result of surface fatigue due to inclusion of graphite particles and repeated abrasion by sand particles. The fiber fracture is due to abrasion and transverse bending by sharp abrasive particles, resulting in fragments of fibers torn from the matrix. In case of G-V composites, a general and dominant feature observed on the surfaces was the generation of cracks in the direction normal to the abrading direction. However, cracks on the matrix, fiber removal, fiber/matrix debonding and fiber breakages are more in graphite-SiC filled G-V composite than SiC-filled G-V composites.

4.0 CONCLUSIONS

The abrasive wear studies of G-V, Gr-SiC-G-V and SiC-G-V composites have been studied. Abrasive wear volume increases with increase in abrading distance/ loads for all the samples. Abrasive wear rate is higher in glass fiber reinforced vinyl ester composite as compared to graphite-SiC loaded glass-vinyl ester composite. However, the SiC-filled G-V composite showed better abrasive wear resistance. The addition of graphite in G-V composite was not improved the abrasive wear performance. SEM feature show matrix and fiber debris, the extent of which depends on system, load and abrading distance involved.

Acknowledgements: The authors are grateful to the Aeronautical Research & Development Board (ARDB), Delhi for funding. The authors are grateful to Dr. S. Seetharamu, Central Power Research Institute, Bangalore and thankful to the CPRI Management for permission to publish this paper.

5.0 REFERENCES

1. Hutchings I.M., “Tribology; Friction and wear of engineering materials”. (CRC Press, London, 1992, pp.156-162).
2. Harsha A.P., Tewari U.S., “Tribo performance of polyaryletherketone composites”, Polymer Testing, **21**(1), 697-709 (2002)
3. Chand N., Naik A., Neogi S., “Three-body abrasives wear of short glass fiber polyester composite”, Wear, **242** No.1, 2000, pp. 38-46.
4. Lhymn C. “Effect of normal load on the specific wear rate of fibrous composites”, Wear, **120** (1), 1-27 (1987).
5. Suresha B., Chandramohan G., Siddaramaiah, Sampathkumaran P., Seetharamu S., **“**Three-body abrasive Wear behaviour of Carbon and Glass fiber Reinforced Epoxy Composites”, J. Mater. Sci. and Engg. A, **443**, 285-291 (2007).
6. Lancaster J.K., In “Polymer Science: a Material Science Hand Book,” edited by A.D. Jenkins (North Holland, Amsterdam, 1972) pp. 959.