Indian Journal of Engineering & Materials Sciences
Vol. 22, December 2015, pp. 669-678

Experimental investigation of cenosphere particulate filled E-glass fiber reinforced vinylester composites under dry and water lubricated sliding conditions

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Received 26 May 2014; accepted; accepted 2 July 2015

The aim of this work is to study the effect of cenosphere particulate on the tribological characteristics of glass fiber reinforced vinylester composites under dry and water lubricated sliding conditions. A synergistic effect is found for the combination of fiber and filler which lead to the improved tribological properties under dry and water lubricated sliding conditions. Effects of applied normal loads, sliding speeds and particle content on the tribological behaviour are also discussed. The experimental results show that the coefficient of friction and specific wear rate decrease with the increase in applied normal load and sliding speed. The experimental results also show that the composites exhibit lower coefficient of friction and lower wear resistance under water lubrication condition than under dry sliding. To validate the experimental data the morphologies of the worn surfaces are carried by means of scanning electron microscope (SEM).

Keywords; Composite materials, Water lubrication, Tribology, Wear

The polymer composites reinforced with different fibers have gained important in many industries. These fibers reinforced polymer composites have certain potential attractive characteristics including high strength, stiffness and good corrosion resistance[1,2]. For a polymer composite material a proper selection of the resin and reinforced material can lead to composite with a combination of high strength and modulus comparable to or even better than that conventional metallic material. Due to the good combination of properties, fiber reinforced polymer composites could be used for many applications such as chemical industry, construction and automobile industry. The role of fiber reinforcement in reducing the specific wear rate of polymers has been widely reported by various researchers[3,4]. The glass fibers are economical and reasonable in performance and therefore the choice of researchers. Many researchers have studied the effect of fiber orientation on coefficient of friction and wear rate of different composites under dry sliding conditions[5]. Many researchers[6-9] have found that a variety of fillers addition such as Al_2O_3, TiO_2, SiC, ZnO, CuO, fly ash and glass fiber reinforcement can improve mechanical properties as well as wear resistance of polymers composite under dry conditions. It is also found that the glass fiber reinforced with vinylester matrix, the wear rate of glass fiber reinforced composite material depends on experimental parameters such as normal load, sliding speed, sliding distance. The load is the most effective factor on the wear rate than the sliding speed under dry sliding conditions. Fuchs ***et al***.[10] demonstrated that fiber reinforced polymer composite technologies offered a way of light weighting the vehicle. Kishore ***et al***.[11] found the influence of sliding velocity and load on the coefficient of friction and wear rate of glass fiber composite filled with rubber. They reported that the wear loss increased with increasing in normal load and sliding speed. Arivalagan ***et al***.[12] studied that the hybrid composite is very effective in reducing friction and wear rate of epoxy composite. Kumaresan ***et al***.[13] studied the friction and wear behavior of silicon carbide filled carbon reinforced epoxy composite. They found that the higher wear loss recorded by increases load and sliding velocity. They also concluded that the incorporation of SiC in composite improved the mechanical properties.

The above stuies were related to the friction and wear rate of polymer composites sliding against steel under dry sliding conditions. In addition, some researchers demonstrate their work on the friction and wear rate of the polymer under water lubricated

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sliding conditions[14-17]. Many researchers[18-20] reported that the fluids such as water and other solutions reduce the formation of transfer films of polymer composite debris on the counter face and the wear rates are greater than those obtained in dry conditions. It is also found that the absorption of water may cause reduction in strength but increase in the elongation and swelling of the surface layer[21-23]. The water into the interface of composite specimens sliding against counterface generally reduces the coefficient of friction, but may increase the specific wear rate of polymer composite. Chauhan ***et al***.[24] found that the coefficients of friction under water lubricated conditions are lower than that of the dry sliding conditions. It is also found that lowest wear rate achieved in dry conditions as compared to water lubricated sliding conditions. Unal and Mimaroglu[25] extensively investigate the water lubricated tribological performance of carbon reinforced PEEK composite. They found that the coefficient of friction under water lubricated condition is lower than that the dry sliding condition. Sirong and coworkers[26] studied the friction and wear behaviors of polyamide 66 and rubber filled composites. They found that the coefficient of friction of composites under water lubricated condition are lower than those under dry sliding conditions, the wear mass losses are higher than those under dry sliding conditions.

From the literature review, it is seen that the majority of investigations conformed their results on friction and wear of glass fiber reinforced polymer composite under dry sliding conditions only. The objective of this research work is to investigate the influence of cenosphere particle on friction and wear behavior of glass fiber reinforced vinylester composites using a pin-on-disc under both dry and water lubricated sliding conditions. Another objective of this work is to study the effect of applied normal loads, sliding speeds and particle content on the tribological behavior of the composites. An experimental study of friction and wear behavior of glass fiber reinforced vinylester composite at different sliding speeds and applied normal loads. The wear mechanism under water lubricated condition was compared with under dry sliding condition.

Experimental Procedure

Materials used and fabrication of composite laminates

E-glass fiber reinforced composites were manufactured in the laboratory by conventional hand layup technique. The E-glass fibers (elastic modulus 72.5 GPa, density 2.59 g/cc) were used as reinforcement and the resin used in this work is commercial vinylester resin (density 1.23 g/cm^3) supplied by Northern Polymer Ltd., Delhi, India. The filler material used is cenosphere (hardness 5-6 MOH, density 0.4-0.6 g/cm^3,) supplied by Cenosphere India Pvt. Ltd. Cenospheres are inert hollow silicate spheres. The shape of cenosphere is spherical and the colour is light gray. The chemical composition of cenosphere is SiO_2- 55%, Al_2O_3- 34%, Fe_2O_3- 1.5%, TiO_2- 1.2%, carbon dioxide- 70%, nitrogen- 30%. The cobalt naphthnate 1.5% (as accelerator) is mixed thoroughly in vinylester resin followed by 1.5% methyl ethyl ketone peroxide (MEKP) as a hardener to prior to reinforcement. The fiber loading (weight fraction of fiber in the composites) is kept at 50wt% for all the samples. The cenosphere filler (90 µm) is mixed with vinylester resin laid on fiber mats. The alternative layers of resin and reinforcement can be laid on the mold sheet. The brush and roller can be used to impregnate the fiber with the resin. A metal roller was used to compact the laminate so that uniform thickness could be obtained. After obtaining thickness of 3 mm, the top of laminates was covered by the mould sheets which were coated with release agent (silicon spray) for ease to separate after curing. The cast of each composite is cured under a load of about 60 kg for 24 h at room temperature before it is removed from the mould. The laminates of sizes 200 × 200 × 3 mm were prepared. The specimens of suitable dimension were cut using the jigsaw cutter for mechanical and wear tests. The composition and designation of the composites prepared for this study are given in Table 1.

Characterization

The friction and sliding wear performance evaluation of E-glass fiber reinforced vinylester composites (C_0) and cenosphere particulate filled glass fiber vinylester composites (C_1, C_2, C_3 and C_4) under dry and water lubricated conditions, the wear tests were carried out on a pin-on-disc type friction and wear monitoring test rig (DUCOM) as per ASTM G 99. The counter body is a disc made of hardened ground steel (EN-32, hardness 72 HRC). The tests were conducted on a track with a diameter of 100 mm and surface roughness of 0.2 µm by selection of the test duration, applied normal load and sliding speed. Before and after testing, the two faces of composite

Table 1 – Designation of unfilled and cenosphere particulate filled glass fiber reinforced vinylester composites

Sample	Composites specification	Load (N)	Sliding speed (m/s)
C_0	50wt% Vinylester + 50wt% Fiber	10	1.9
		40	3.9
		70	5.7
C_1	Vinylester + 50wt% Fiber + 5wt% cenosphere +	10	1.9
		40	3.9
		70	5.7
C_2	Vinylester + 50wt% Fiber + 10wt% cenosphere +	10	1.9
		40	3.9
		70	5.7
C_3	Vinylester + 50wt% Fiber + 15wt% cenosphere	10	1.9
		40	3.9
		70	5.7
C_4	Vinylester + 50wt% Fiber + 20wt% cenosphere	10	1.9
		40	3.9
		70	5.7

samples were cleaned using acetone. The specimen was held stationary and the disc was rotated while a normal force was applied through a lever mechanism. During the test friction force ($\boldsymbol{F}_f$) was measured by a transducer mounted on the loading arm. The friction force readings were taken as the average of 100 readings every 40 s for the required period. For this purpose a microprocessor controlled data acquisition system was used. A series of test were conducted with three sliding velocity of 1.9, 3.9 and 5.7 m/s under three different applied normal loads of 10, 40 and 70 N. The environmental conditions in the laboratory were temperature 27°C and 52% relative humidity. The specific wear rate was obtained simply by measuring the weight loss of the samples as a function of time.

During these experiments initial and final weight of the specimens was measured. The specimens were weighted both before and after the tests to an accuracy of ±0.01 mg in a precision balance. The specific wear rate (mm^3/Nm) is then expressed on 'volume loss' bases:

$$\boldsymbol{K_S} = \frac{\Delta \boldsymbol{M}}{\boldsymbol{L F_n}} \qquad \dots (1)$$

Where $\boldsymbol{K}_s$ is the specific wear rate (mm^3/Nm), $\Delta \boldsymbol{M}$ is the mass loss in the test duration (g), ρ is the density of the composite (g/cm^3), $\boldsymbol{F}_N$ is the average normal load (N) and $\boldsymbol{L}$ is the sliding distance (m).

Scanning electron microscope (SEM) was used to analyze the composites structure and worn surfaces. Composite specimens for documenting composite structures were polished before cleaning. All samples are prepared by removing loose debris by cleaning with acetone and finally coated. Worn surface samples were mounted on the aluminium stub conductor (silver) paint and were sputter coated with gold prior to SEM examination. The surfaces of the samples were examined directly by scanning electron microscope (FEI quanta FEG-450). The energy dispersive spectroscopy (EDS) attached with the SEM was used for analysis of the specimens.

Results and Discussion

Effects of applied normal load and sliding speed on coefficient of friction

The detailed compositions of the materials taken for the test conditions and parameters considered for experimentation scheme are presented in Table 1. Figures 1 and 2 present the variation of coefficients of friction with applied normal load values (10, 40 and 70 N) at different sliding velocity of (1.9, 3.9 and 5.7 m/s) under dry and water lubricated sliding conditions of E-glass fiber reinforced vinylester composite (C_0) and cenosphere particulates filled E-glass fiber reinforced vinylester composite (C_1, C_2, C_3 and C_4). From the observations of Fig. 1 it is seen that the coefficient of friction decreases with increase in applied normal load for unfilled and filled E-glass reinforced vinylester composites at sliding speed of 5.7 m/s both under dry and water lubricated conditions. It was found that as increasing applied normal load increases the temperature at the interface under dry sliding conditions. This increase in temperature at the sliding interface causes thermal softening of the matrix, which results in weakness in bond at the fiber matrix interface. As a result fiber becomes the loose in the matrix and shear easily due to axial thrust. As a result coefficient of friction decreases[24]. However, under water lubricated conditions the presence of water at the interface as lubricated the effect of temperature and friction mechanism at the interface is predominated by the occurrence of hydrodynamic film thickness and due to this reason coefficient of friction reduces[23,25]. It is seen that all the cenosphere filled glass fiber reinforced composites show better friction reducing ability at higher load than the unfilled glass fiber reinforced vinylester composites under water lubricated conditions. In all test conditions the coefficient of friction was maximum in case of unfilled glass fiber reinforced vinylester composites (C_0) under dry sliding conditions and minimum in case of 10 wt% cenosphere

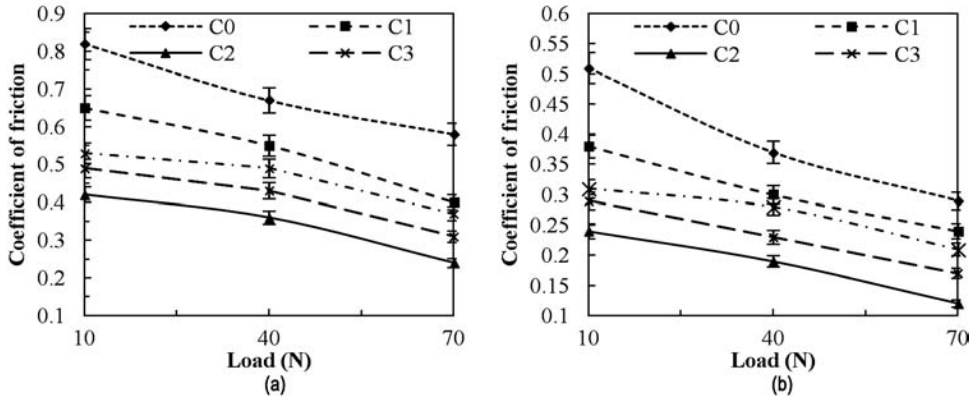

Fig. 1 – Variation of coefficient of friction of the glass fiber reinforced vinylester composites at 5.7 m/s (a) under dry conditions and (b) under water lubricated conditions

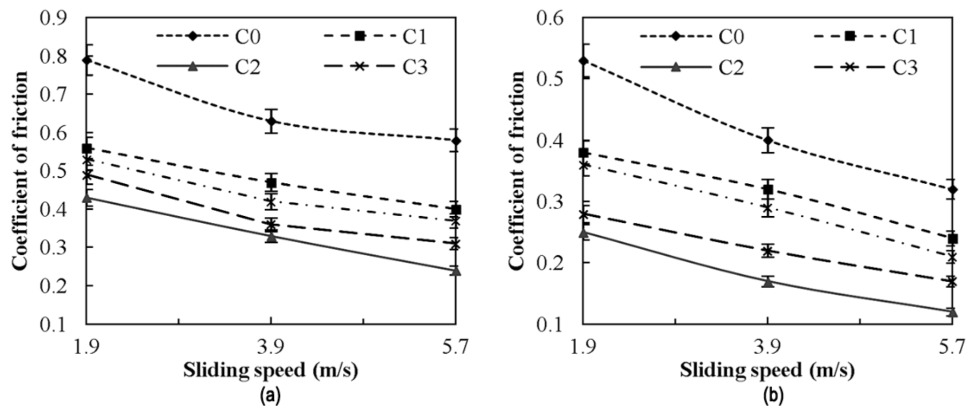

Fig. 2 – Variation of coefficient of friction of the glass fiber reinforced vinylester composites at normal load 70 N of (a) under dry conditions and (b) under water lubricated conditions

filled glass fiber reinforced vinylester composites (C_2) under water lubricated conditions. The cenosphere filled glass fiber reinforced composites with filler content (10 wt%) show the better load carrying capacity than the unfilled glass fiber composites under water lubricated conditions.

Figure 2 shows the effect of the coefficient of friction on sliding speeds of glass fiber reinforced vinylester composites under dry and water lubricated sliding conditions. It is observed that with increasing sliding speeds under dry and water lubricated conditions the coefficient of friction decreases. However in dry and water lubricated sliding conditions the coefficient of friction has higher value 0.82 at the applied normal load 70 N and sliding speed of 5.7 m/s under dry sliding conditions and lower value 0.12 at the normal load 70 N and sliding speed of 5.7 m/s under water lubricated conditions. It is clear that a low coefficient of friction could be achieved at high sliding speed. Mainly the presence of water in the friction surface could result in fluid film lubrication, boundary lubrication, or combination of both. Speed is important not only because of its major role in both the viscoelastic response to stress and the generation of friction heat, but also because the lubricated model is partly determined by the sliding speed[24]. A hydrodynamic lubricating film could be formed at high speed. Actually at low speed the lubricated wear rates of some polymers are approaching the values characteristic of unlubricated sliding and thus lubrication is becoming almost ineffective. The low coefficient of friction might result from the effective lubrication came from the high speed[25,26].

The higher coefficient of friction is due to the fact that easy detachment of softened vinylester resin from the reinforcement and more breakage of glass fiber reinforced under dry sliding conditions. A large variation observed between dry and water lubricated sliding conditions. Underwater lubricated sliding conditions, the swelling of surface layers decreased the shear strength of the composite, therefore reducing the coefficient of friction. Moreover, due to the boundary lubrication effect of the water absorbed layer. Water was not only a type of polar lubricant to reduce the direct contact between specimens and counterface, but also a cooling fluid to dissipate the frictional heat during the sliding. Therefore, the coefficient of friction of glass fiber reinforced vinylester composites was lower in lubricated condition than in dry sliding condition[23,24, 26]. Also water acted as a lubricant and could form a lubricant film in the contact region during sliding friction, which led to that coefficient of friction under water lubricated condition were lower than those under dry sliding condition[24].

Effects of applied normal load and sliding speed on specific wear rate

Figures 3-5 present the variation of specific wear rate for unfilled (C_0) and cenosphere particulate filled glass fiber reinforced composites (C_1, C_2, C_3 and C_4) with applied normal load of 10, 40 and 70 N and sliding velocities of 1.9, 3.9 and 5.7 m/s under dry and water lubricated conditions. It is evident that the increase of cenosphere content from 5 to 20 wt% led to a significant decrease of specific wear rate. This kind of variation has been reported for glass fiber reinforced epoxy composites under dry sliding conditions[26]. Figure 3 shows the effect of loads on specific wear rate for unfilled and filled glass fiber reinforced vinylester composites under dry and water lubrication sliding conditions at sliding speed 5.7 m/s. It is observed that the specific wear rate of the glass fiber reinforced vinylester composites decreases with increasing applied normal load both under dry and water lubrication sliding conditions. From the observations of Fig. 3, it is seen that the specific wear rate decreases with increase in applied normal load conditions. The highest wear rate is for unfilled glass fiber reinforced vinylester composite (C_0) under dry sliding conditions with the value of 0.42×10^{-6} mm^3/Nm at sliding speed 1.9 m/s and applied normal load of 10 N. The lowest

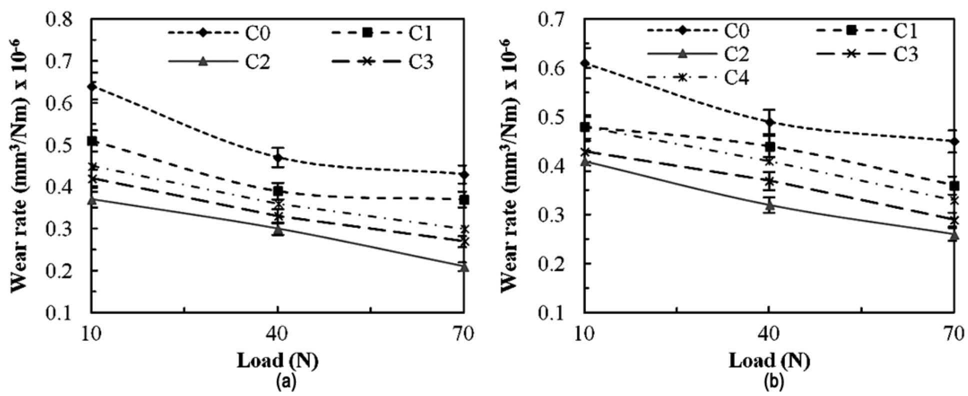

Fig. 3 – Variation of specific wear rate of the glass fiber reinforced vinylester composites at 5.7 m/s of (a) under dry sliding conditions and (b) under water sliding conditions

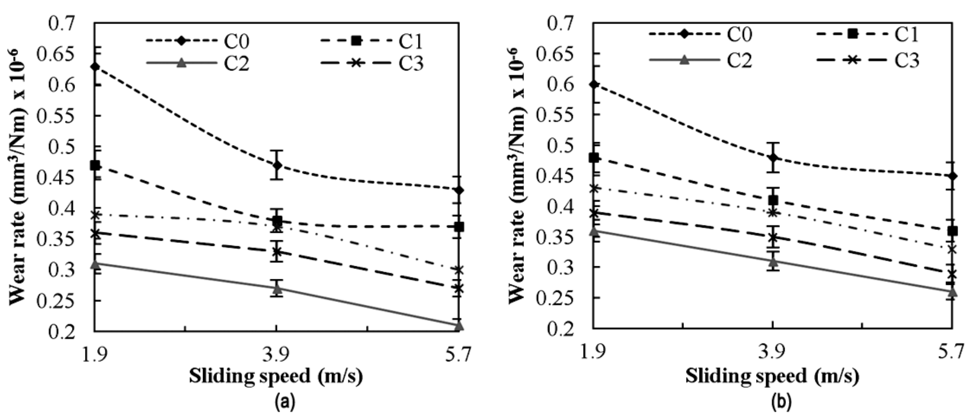

Fig. 4 – Variation of specific wear rate of the glass fiber reinforced vinylester composites at 70 N of (a) under dry sliding conditions and (b) under water sliding conditions

specific wear rate is 0.22×10^{-6} mm^3/Nm for glass fiber reinforced vinylester composite (C_2) composite at 5.7 m/s sliding speed and applied normal load of 70 N under water lubrication conditions. The film layer is removed under water lubricated conditions. Underwater lubricated conditions the transfer layer of glass fiber and matrix debris was formed on counterface. These transfer layers formed on counter faces were very close under dry conditions[24,26]. The lowest specific wear rate for filled glass fiber reinforced vinylester composites (C_2) is achieved at 70 N under dry conditions. Improved wear resistance was obtained by the addition of cenosphere filler. During sliding the cenosphere particles get smeared at the interface, forming a thin film on the counterface, which in turn reduces the specific wear rate. The addition of glass fiber and cenosphere particles strengthened the combination of the interface between the reinforcement and the vinylester resin[26]. Due to this reason the specific wear rate was reduced under dry sliding conditions.

Figure 4 shows the effect of specific wear rate on sliding speeds of unfilled and filled glass fiber reinforced vinylester composites under dry and water lubrication sliding conditions at applied normal load 70 N. From the observations of Fig. 4, it is seen that the specific wear rate decreases with increase in sliding speeds both under dry and water lubricated sliding conditions. The highest specific wear rate is for unfilled composite (C_0) under dry conditions with a value of 0.64×10^{-6} at 1.9 m/s sliding speed and normal load 10 N. The lower wear rate is 0.18×10^{-6} mm^3/Nm for filled glass fiber reinforced vinylester composite (C_2) under dry sliding conditions at 5.7 m/s sliding speed and normal load 70 N. The lowest value of specific wear rate under water lubricated sliding conditions is 0.26×10^{-6} mm^3/Nm for glass fiber reinforced vinylester composite (C_2). It was observed that the water might induce an increase in the chemical corrosion wear of the stainless steel counterfaces, which would lead to a higher wear rate of unfilled and cenosphere particulate filled glass fiber reinforced vinylester composites under water lubricated conditions than under dry sliding conditions[23,24].

Microstructure analysis

Figure 6 presents the scanning electron microscope images of worn surfaces of unfilled glass fiber

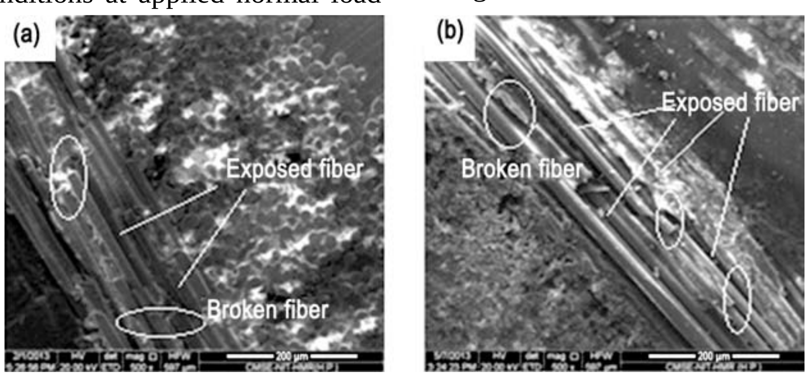

Fig. 5 – SEM pictures of the worn surface of composite specimens (C_0) at applied normal load 70 N and sliding speed 5.7 m/s (a) under dry sliding condition and (b) under water lubrication sliding conditions

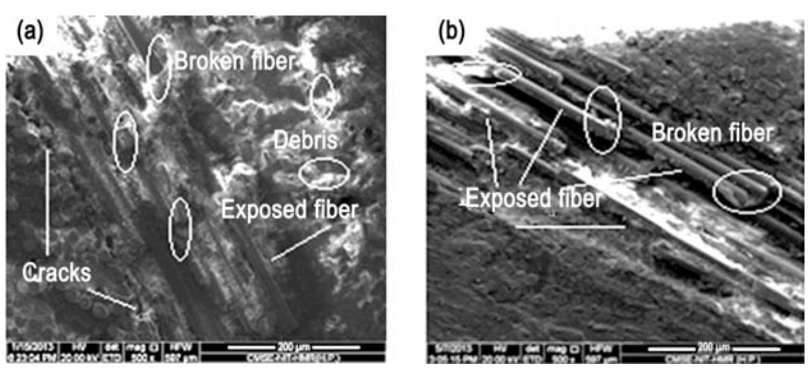

Fig. 6 – SEM pictures of the worn surface of composite specimens (C_1) at applied normal load 70 N and sliding speed 5.7 m/s (a) under dry sliding condition and (b) under water lubrication sliding conditions

reinforced vinylester composites (C_0) at applied normal load 70 N and 4 m/s sliding speed under dry and water lubricated sliding conditions. It is seen that the glass fiber are pulled out from the fiber matrix on the worn surface of the unfilled glass fiber reinforced vinylester composites (C_0) under dry sliding conditions as shown in Fig. 5(a). Also this figure shows the more breakage of fiber, more exposure of fibers and debris are observed. On the other hand under water lubricated conditions from SEM image in Fig. 5(b) fiber exposure and less debris are observed which indicates the small specific wear rate. These observations related to the experimental finding as shown in Fig. 4. Similarly Fig. 6 (a) and (b) are SEM pictures of composite specimens (C_1) under dry and water lubricated sliding conditions. The fiber exposures are more in case of dry sliding conditions, hence more wear occur. Underwater lubricated conditions the breakage of fiber is less, hence lower wear rate occurs. However, from the SEM picture Fig. 7(a) for composite samples (C_2) shows the worn surface under dry sliding conditions is smooth and exposures of the glass fibers are invisible, hence lower wear rate but Fig. 7(b) shows the matrix is uniformly spread over a major portion of the specimen exposure of glass fiber are more, hence higher wear rate under water lubricated sliding conditions and these observations correlate with experimental findings as shown in Fig. 4. This is because the film is not formed due to the presence of water at the interface. The figure also shows the uniform distribution of matrix completely masking the reinforcement. The transfer film on the counterface slide against composite specimen (C_2) is much smooth, uniform and shows no sign of scuffing under dry sliding conditions. The wear debris tend to accumulate near the glass fiber and act as lubricant film, then avoid the glass fiber from further fracture such as a film may be accounted for a reduce in wear rate. Also the fiber removal plays a significant role in the wear mechanism. Because the matrix would be subjected to more intensive micro-ploughing and micro cutting and more wear of the matrix could occur after the fiber peeling-off from the surface. A wear track is clearly visible in micrograph under dry sliding conditions. Figures 8 and 9 represents the micrographs of composite specimens (C_3 and C_4), these composites show moderate wear which results in breakage of composites at distinct places due to the combination of wedge formation and ploughing mechanism of abrasive wear under dry sliding conditions. The transfer film on the worn surface of the counterface against the composite specimens (C_3 and C_4) is a rough and shows sign of scuffing, which leading to the decreases wear resistance. These figures also show the less debris formation is only in few patches, fiber exposure also in less quantity under water lubricated sliding conditions.

The interface debonding is also detected due to the stress concentration which corresponds to the poor tribology properties. Once the fibers are removed from the matrix, they will rub the matrix in the following sliding process. Even more, when the fibers are removed from the matrix, they can cause further breakages of fibers. Those may result in a high wear rate. In short, the interface debonding, fiber fractures, fiber crushes and cavities left after peeling off of fibers seem to be the main characters of this micrograph. These observations from SEMs of the worn surfaces very well confirm to the experimental results depicted in Figures 3 and 4.

Under dry sliding conditions the transfer layer of glass fiber and matrix debris was formed on counterface. These transfer layers formed on counter

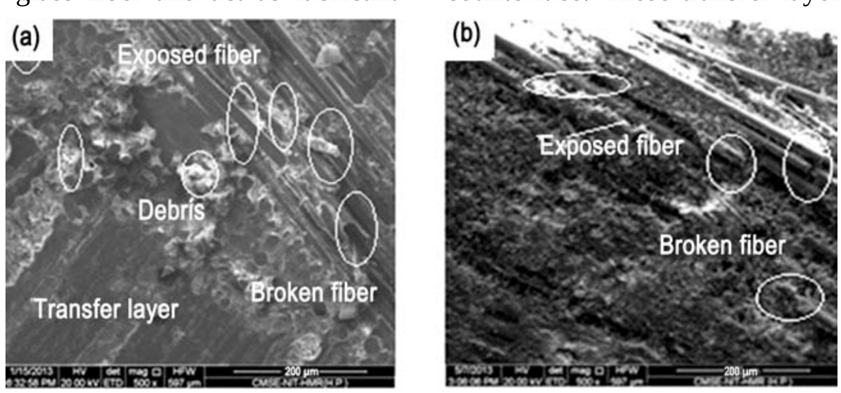

Fig. 7 – SEM pictures of the worn surface of composite specimens (C_2) at applied normal load 70 N and sliding speed 5.7 m/s (a) under dry sliding condition and (b) under water lubrication sliding conditions

faces were very close under dry conditions. The transfer layer is removed under water lubricated sliding conditions. During sliding the cenosphere particles get smeared at the interface, forming a thin film on the counterface, which in turn reduces the specific wear rate. Due to this reason the specific wear rate was reduced under dry sliding conditions than that of the water lubricated conditions. This is may be also attributed to the reason the transfer film on counterface fails to form and the slide occurred direct between the specimens and counter surfaces during sliding. The absorbed water lowered the strength of the composites and also inhibited the formation of transfer layers on the counterfaces resulting in the less wear resistance

Energy dispersive spectroscopy (EDS) analysis of the worn surfaces of cenosphere particulate filled glass fiber reinforced vinylester composites were carried out both the dry and lubricated wear conditions. The EDS spectroscopy of the worn surface of cenosphere filled glass fiber reinforced vinylester composites tested at a applied normal loads 10 N and 70 N and sliding speed of 5.7 m/s is shown in Figs 10(a) and 10(b), respectively. It may be noted that the peak corresponding to Fe is significantly stronger in case of 10 N as compared to that of 70 N. The EDS spectroscopy of composite tested at 70 N in dry condition exhibits almost a similar pattern to that observed in Fig. 10(b). These results reveal that during dry sliding wear more counter surface materials get transferred to the composites at lower load 10 N as compare to that 70 N. The extent of transfer of counter surface material to the worn surface is almost invariant to the sliding velocity. Under lubricated sliding condition, the peak corresponds to Fe in the EDS pattern is very faint as shown Fig. 10(b). A mass of chemical element of Fe were found in the surface of specimens, which proved the transfer of steel element to the worn surface of specimens. The amount of transfer would be dependent on the composition of specimens. It is demonstrated that under water lubricated condition very less amount of counter surface material gets transferred and the friction between two counter surfaces is minimized significantly.

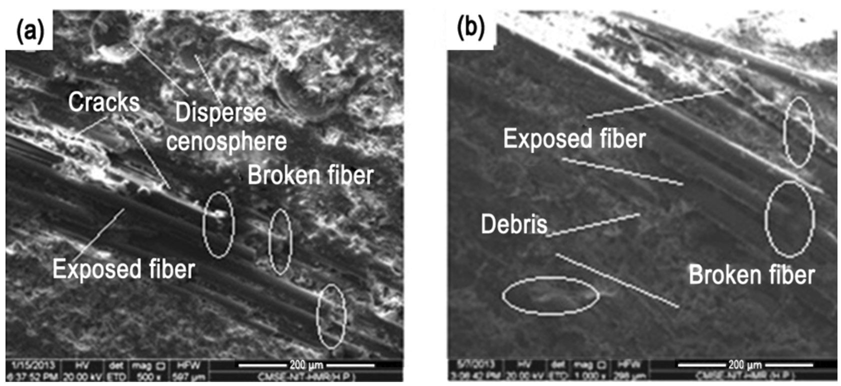

Fig. 8 – SEM pictures of the worn surface of composite specimens (C_3) at applied normal load 70 N and sliding speed 5.7 m/s (a) under dry sliding condition and (b) under water lubrication sliding conditions

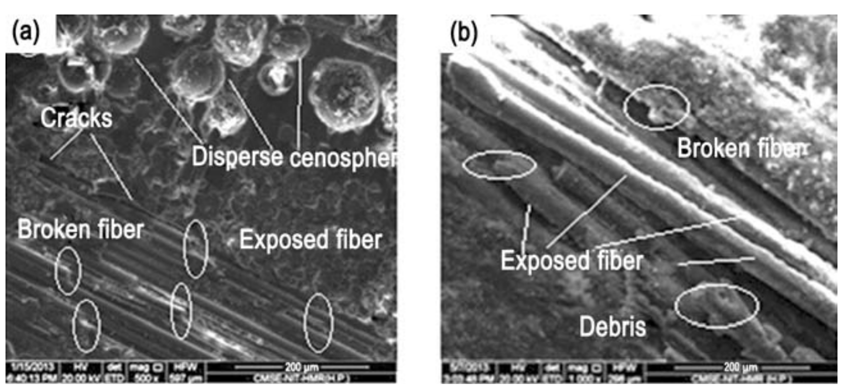

Fig. 9 – SEM pictures of the worn surface of composite specimens (C_4) at applied normal load 70 N and sliding speed 5.7 m/s (a) under dry sliding condition and (b) under water lubrication sliding conditions

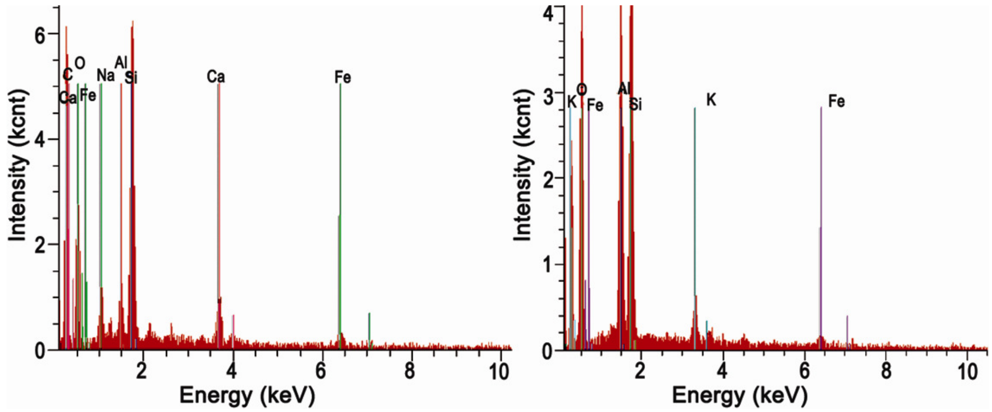

Fig. 10 – EDS spectrograph of cenosphere filled (10 wt%) glass fiber reinforced vinylester composites at applied normal load 70 N and sliding speed 5.7 m/s (a) under dry sliding condition and (b) under water lubricated sliding condition

Conclusions

The following conclusions can be drawn from this study:

(i) The coefficient of friction of unfilled and cenosphere particulates filled E-glass fiber reinforced vinylester composites decrease with increase in applied normal load and sliding speed under dry as well as water lubricated sliding conditions. The coefficient of friction for composite specimens are lower under water lubricated sliding conditions as compare to the dry sliding conditions.

(ii) The specific wear rate decreases with increase in applied normal load and sliding speeds for particulate filled E-glass fiber reinforced vinylester composites. The composite specimens (C_0) have higher specific wear rate and cenosphere filled composite specimens improves the wear rate both under dry and water lubricated conditions. It is also found that the lowest specific wear rate achieved in dry conditions than that of the water lubricated conditions. This effect becomes more significant for the cenosphere particulate content is 10 wt%.

(iii) The highest specific wear rate is unfilled glass fiber reinforced vinylester composite under dry condition 0.82×10^{-6} mm^3/Nm at load of 10 N and sliding speed of 1.9 m/s. However, the lowest wear rate is 0.18×10^{-6} mm^3/Nm vinylester composite at applied normal load of 70 N, sliding speed of 1.9 m/s under dry sliding condition.

(iv) It is also observed that the specific wear rate for glass fiber reinforced vinylester composites little influenced by the applied normal load and sliding speed but more influence by environmental conditions. SEM morphology study of the fibers shows a smooth surface after the addition of composites at 10 wt%.

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