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Wear Performance of Cylindrical Shaped Alumina Nanoparticles Filled Epoxy Composite

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Abstract

Low cost high specific strength epoxy LY 556 and alumina nano filler is utilized in current research for developing a epoxy composite. A liquid dispersion method was adopted for fabricating epoxy alumina composite having 0.50 wt% of alumina reinforcement. For uniform and homogenous dispersion of reinforcement, ultra-sonification of 120 W is adopted. To study the effect of particle behavior, unfilled epoxy and 0.5 wt.% cylindrical alumina oxide filled epoxy composite were used. The cylindrical-shaped alumina oxide with a diameter in the range of 5–10 nm and length of less than equal to 50 nm was used. Dry sliding wear experiment on the pin–on–disc was performed to evaluate friction and sliding wear performance of unfilled epoxy and epoxy filled by cylindrical-shaped filler in short term and long term. In the present investigation, 2000 m distance (short term) and 4000 m distance (long term) were the sliding distance opted. The applied forces are 20 N and 30 N is applied during testing and velocity of sliding is 1.26 m/sec is taken as same throughout the experiment. As load enhanced there is a decrement in coefficient of friction, stable transfer film may be the reason for the same. Maximum decrease in COF is at low sliding distance of 2000 m at 30 N applied load is 60%.

Keywords: Friction, Epoxy composite, Cylindrical shaped alumina oxide, Dry sliding wear, Coefficient of friction

INTRODUCTION

With the advent of time, there has been an increase in the use of polymer composite in the aerospace industry as a doment material for making structures. It also used as alternative low weight material as a specific requirement of automotive and chemical industries. The properties that make the polymer composites suitable for industrial applications are obtained by adding or reinforcing different and special fillers having different shapes, sizes, and volume fractions. To attain the anticipated mechanical and tribological performance of the polymers, various types of fabrics, short fibers, and particulates are being introduced in some polymer matrices, of different sizes, shapes, and varying volume fractions. Friction and wear performance of polymeric material are influenced by extent of nanoparticle filler introduced into the composite. The behavior of the polymer matrices can be changed by the introduction of nanoparticles in different ways. Incorporation of the same means lowering (COF) at the same time decreasing wear (WR) of fabricated material. Friction and wear performance of any polymer by incorporation of nanoparticles may be positive or detrimental to the composite. This behavior depends on the components and type of the nano-fillers and traditional fillers. Excellent mechanical and tribo behavior of nano-sized filled composite is an outcome of exponentially higher sp. The surface

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area of nano-sized filler, results in higher interfacial filler matrix bounding To improve the performance of the polymer composite various types of fillers and reinforcements have been incorporated into the polymer matrix [1–6]. Friction leads to wear or progressive and continual degradation of counter components material leading to complete failure of them.

An exhaustive study conducted by Abenojar et al concluded that the wear rate of clear resin stabilizes after a certain time but the wear rate of 0.3% silica-added nanocomposite does not stabilize [7]. Akinci et al. claimed from their experiment that there is an increase in the coefficient of friction resulting from applied loads, sliding speed, and an increase in ZrO_2-filled PMMA composites. Also, with an increase in ZrO_2 filled PMMA composite wear rate decreases. The addition of ZrO_2 with PMMA also results in a decreased wear rate [8]. Bhimaraj et al. concluded that the average COF and WR decrease by the addition of 2 wt.% of 38 nm Al_2O_3 in PET composite. Also, at low wt.% reinforcement, the condition filler is insufficient to have a positive effect on the wear behavior of the PET/Al_2O_3 composite [9]. Burris and Sawyer suggested that the composite material has a lower COF and WR compared to unfilled PTFE and PEEK. Further, the author reported that the WR increases with an increase in PEEK content [10]. Rahuman et al. investigation confirm that the weight loss and WR increase with the enhancement in time taken to study wear and increase in applied wear force. COF and WR decrease with the addition of jute and glass fiber in neat epoxy [11]. Experimental outcomes publicized that the hardness of alumina nanoparticles increases along with Young's Modulus and compressive strength. COF decreases and wear resistance improves on incorporating a low loading at different loads and sliding times. Also, the load-carrying capacity of the composite increases whereas, the developed shear stress decreases in the present case [12]. FEA is also a method for determining the effect of reinforcement on the propertie of composite [13–14]. Kurahatti et al. suggested that addition of nano- ZrO_2 to BMI decreases the COF and WR by increasing the ZrO_2 content [15]. Vinay and Venkatesh concluded that the increase in filler content decreases the WR [16]. Wang and Pie in their exhaustive study concluded that the reduction in friction and improvement of wear resistance is achieved only when the nanoparticles act as rolling elements between the two bodies [17]. The increment in material loss in abrasive wear is greater with the inclusion of spherical shape filler compared to that of cylindrical shape similar size Al_2O_3 nanofiller in epoxy composite [18]. The epoxy-based composite can also be utilized in human implant fabrication [19]. The mechanical and wear behaviour can be enhanced by the introduction of vaiours reinforcement in the natural fibers [20–24].

The above literature unfolds and shows that the reinforcement wt.% concentration isn't the only parameter that affects the tribology of the polymer composite. The existing resistance to wear by the filled polymer is governed by load, space, and velocity taken for wear. Most of the studies are concentrated on effect of particles volume fraction reinforcement on the wear behaviour of epoxy composites. This paper investigates the outcome of the above variables on the wear behavior of the epoxy reinforced with low wt% of cylindrical Al_2O_3 nano-filler. The effect of reinforcement as well as the effect of sliding distance of the wear behaviour of polymer composite is the special concern of the present study.

EXPERIMENTAL

Material

In the present study, Singhal Chemicals, Meerut supplied Epoxy LY 556, and hardener HY 951 is utilized as matrix. Epoxy and hardener are mixed at a constant ratio of 10:1 by weight. Reinforcement material used is Alumina Oxide (Al_2O_3) of cylindrical shaped rod supplied by Sigma Aldrich India. The average diameter of the filler particle is 5 – 10 nm and the length of the rod is not more than 50 nm. The nano filler used in the composite for study was outsourced and it was only blendde in epoxy in as received condition.

Methodology

The liquid dispersion method is the process adopted for the preparation of epoxy composite filled with cylindrical alumina oxide. For uniform and homogenous dispersion of reinforcement, an ultra-sonification process is adopted. This process is continued for 60 minutes. The hardener is then mixed into the solution and the mixture is now poured into an acrylic mold to get the desired shape of the sample.

The mould is cured for 24 hours and this is followed by post-curing at 100°C for 4 hours. For performing pin–on–disc test, samples were fabricated according to ASTM G-99. In present investigation, two sliding distances of 2000 m and 4000 m were considered. 2000 m is considered to study the effect of reinforcement in short term while 4000 m is for studying long term effect of wear on fabricated material. The sliding velocity of 1.26 m/sec is kept constant whereas the sliding load was taken as 20 N and 30 N. In the present investigation, weight loss is considered for determining the sp. wear rate of the composite.

RESULTS AND DISCUSSIONS:

Table 1 presents a summary of the compiled values of pin–on–disc test parameters.Standard equations were utilized for evaluation sp. wear rate (eq.1 below) and COF [5].

$$W_{sp} = \frac{\Delta M}{\rho N D} \tag{1}$$

Where, ΔM-resultant loss of mass,
ρ-density,
N-normal applied load,
D-sliding distance.

Integrated display inbuilt in tribometer provides the online value of frictional force, COF is then evaluated from the coulombs friction law equation 2, by taking proportion of frictional force to normal reaction.

$$F = \mu N \tag{2}$$

From the Table 1, it is clear that on increasing the sliding distance specific wear and COF also increase. The COF of unfilled epoxy and 0.50 wt% cylindrical filled epoxy enhanced by 16% and 10% respectively with enhancement in rubbing distance. The positive gain in the COF might be due to the plowing of more material and the non-formation of a stable transfer layer. Another reason for an increase in COF and sp. wear might be due to the conversion of two-particle wear to three-particle wear.

Deviation of the sp. wear for unblended and 0.50 wt% Al_2O_3 filled epoxy composite is portrayed in Figure 1. The sp. wear rate for unfilled and 0.5 wt% Al_2O_3 filled epoxy composite increases with enhancement in rubbing distance. The percentage decrease in COF and wear is greater in Al_2O_3 filled composite compared to that of unblended epoxy. As already stated the non-formation of a stable transfer layer and less hardness compared to Al_2O_3 filled epoxy composite might be responsible for such behavior. Similar decrease in sp. WR due to inclusion of rigid and hard filler is also reported in literature [25, 26].

Figure 2 indicates the behavior of the unfilled epoxy and the 0.50 wt% cylindrical reinforced alumina oxide. The graph indicates that the Coefficient of Friction (COF) for unfilled and 0.5 wt% Al_2O_3 filled epoxy composite increases with the enhancement in rubbing distance at low and high applied load. The increase is almost same with unblended epoxy and Al_2O_3 filled composite. At higher applied load of 30 N the composite follows the same pattern of increment in COF with increase in sliding distance. Little decreament of COF value is witnessed in unblended epoxy at 30 N applied load at a higher sliding distance. Creation of interfacial layer between the work surface and counter surface may be the reason for such performance.

As evident by graph the increment in WR by applying high load for both the unfilled epoxy composite and 0.50 wt% filled with cylindrical-shaped nanoparticles of alumina oxide. The increase in WR with enhancement in load levels for both unfilled epoxy and alumina oxide inclusive epoxy is due to the inability of the material to counter the ill effects resulted during the counter motion of relatively low hardened material on ounter surface. The counter surface used in the present study is EN31 of 60 HRC as described in the ASTM standard, whereas the hardness of epoxy is comparatively low in value [19]. Since low wt% of filled materials are not able to counter the initiation of crack and its propagation throughout the sliding motion. It can also be observed that increment in WR with increase of applied load on the specimen. It might be possible that the detachment of nano filler particulates is due to piling of concentration of stress at interface. Low interaction bonding between the filler and matrix may be the other reason for increase in wear rate of composite compared to epoxy.

Table 1. Presents the summarized results of wear test.

Sample Name	Distance	Load	Sp. wear rate	COF
Epoxy	2000	20	2.3125×10^{-14}	0.501
		30	2.125×10^{-14}	0.431
	4000	20	1.65625×10^{-14}	0.575
		30	2.27083×10^{-14}	0.240
composite	2000	20	2.375×10^{-14}	0.520
		30	3.45833×10^{-14}	0.171
	4000	20	3.1875×10^{-14}	0.567
		30	2.5833×10^{-14}	0.249

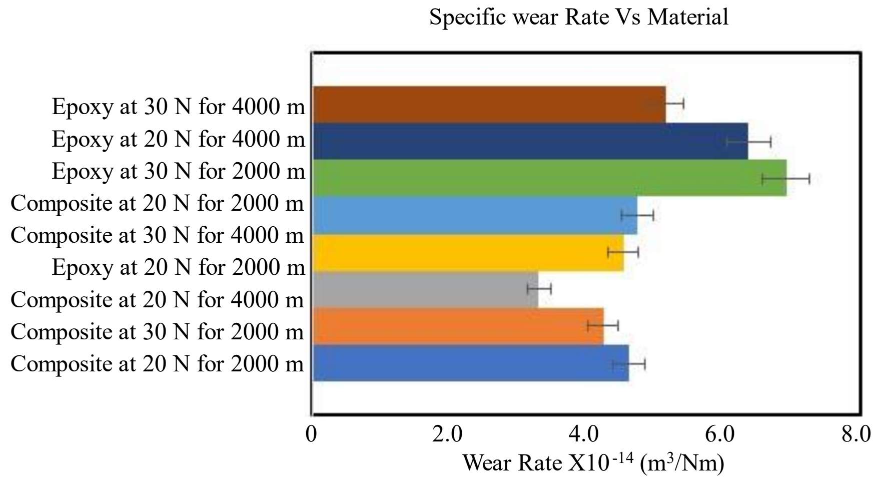

Figure 1. Illustrates the Specific wear of unblended and 0.5 wt% Al_2O_3 filled composite.

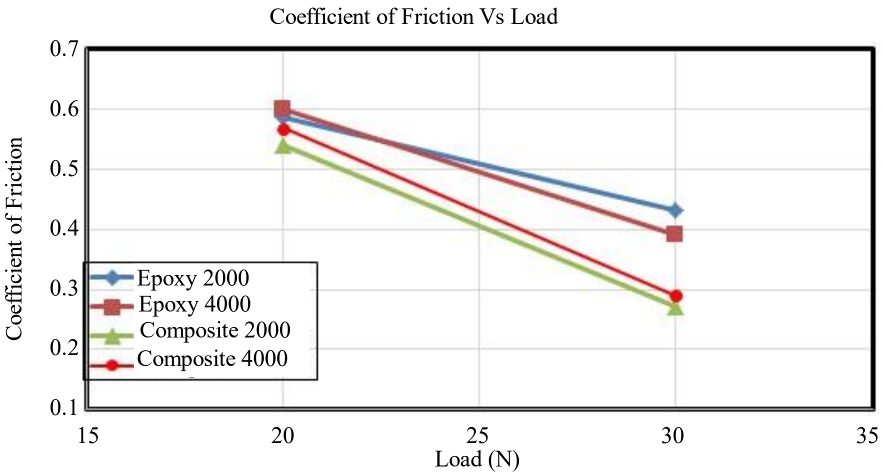

Figure 2. Illustrates the Coefficient of Friction with material and Sliding distance.

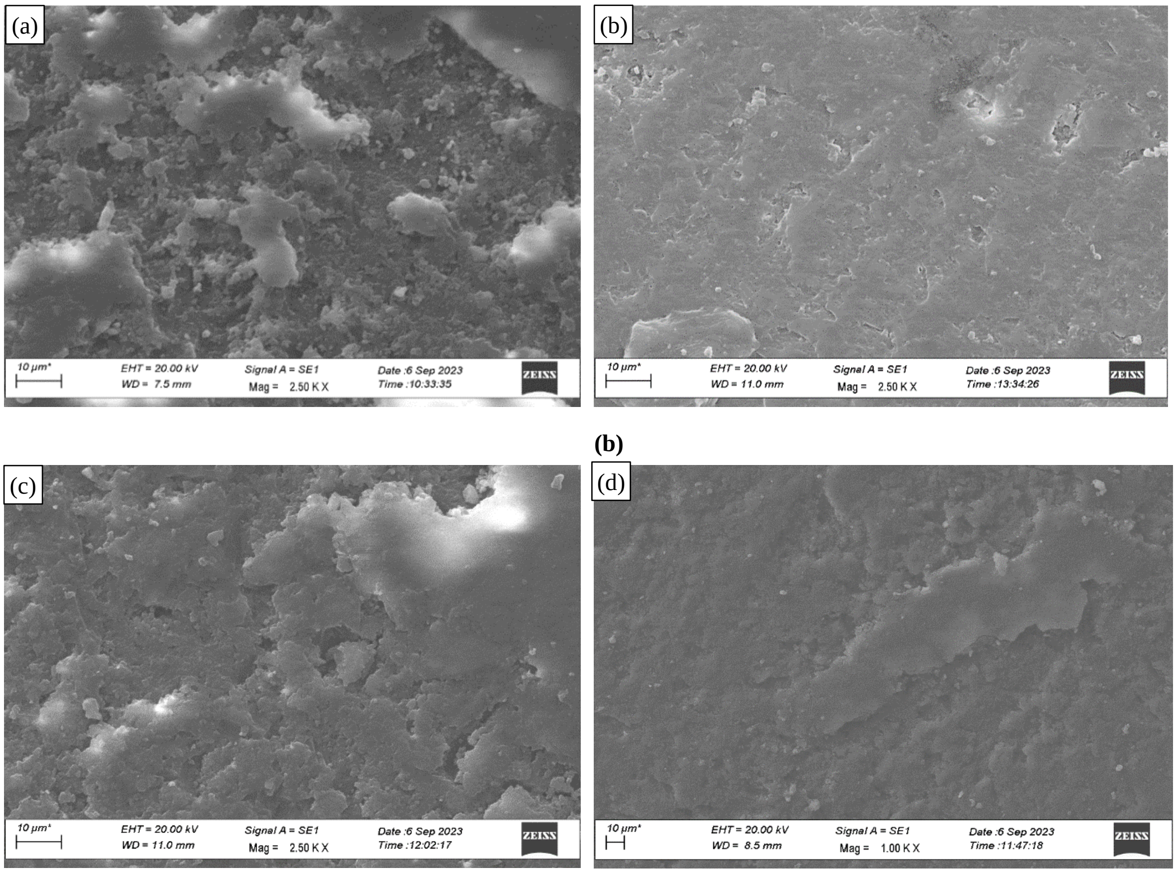

Figure 3. Shows the SEM images at 30 N applied load for unblended epoxy (a) 2000 m (b) 4000 m, and alumina composite (c) 2000 m and (d) 4000 m.

Figure 3 depicts images of scanning electron microscope (SEM) wear-tested samples of unblended epoxy and composite at load levels of 30 N and 2000 m and 4000 m travel respectively. From the SEM images, it is clear that the surface of unblended is featureless whereas the wear surface of composite is flat enough. The low sliding distance (2000 m) the surface of unblended epoxy (Figure 3 (a)) is smooth and has flat surface with more and deeper plowing marks. Whereas the plowing marks on the composite samples are few in number and very shallow. A similar case is with a high sliding distance of 4000 m is observed. The composite material SEM image is featureless and smooth. The wear marks impression are very less visible whereas the wear tracks are clearly visible on unblended epoxy samples along with few deep craters are also visible.

CONCLUSIONS

The epoxy composite is successfully being fabricated with 0.50 wt% cylindrical shaped reinforcement of Al_2O_3 as filler material. Based on the study, the following conclusions were drawn:

- Ultra-sonification method is used for the dispersion of filler particulates, is an excellent method for dispersion of nano filler.
- The COF of the unblended epoxy and epoxy composite improves monotonically with travel distance, whereas on increasing load levels 20 N to 30 N, COF decreases. The decrease in more with composite compared to unblended epoxy.
- Specific WR drops by inclusion of alumina reinforcement in the composite. The decrease in specific wear rate is due to inclusion of hard alumina particulates in epoxy.
- The decrease in sp. WR for both low load application level 20 N as well as higher applied load level of 30 N.

- Deeper and more vigorous plowing marks are clearly visible on the SEM images of unblended epoxy samples compared to alumina composite at low sliding distance 2000 m and high sliding distance 4000 m.
- The mechanical properties of the polymer is enhanced.

Declaration of Interest

No conflict of interest

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