Tribological Investigation of Epoxy Composite with Hard Powder

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Abstract: The development of high performance materials based on epoxy resin finds a growing number of applications in which high wear resistance is required. One major drawback in many of these applications is the relatively poor wear resistance of the epoxy resin. Therefore, in order to investigate on the possibility of increasing wear resistance of thermo set polymers filled with hard powders, sliding tests are carried out by means of a pin on disc apparatus. In particular, composite resins, constituted by an epoxy resin filled with different contents and sizes of Silicon Carbide powder, are analyzed; the wear resistance, in terms of volume loss, is measured for different abrasive counterfaces and loads.

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INTRODUCTION

One of the most common material degradation mechanisms encountered in the engineering industry is the abrasive wear. In particular, two-body abrasive wear is defined as the removal of solid material from a body surface by the sliding action of hard particles of another body. Since the abrasive wear is caused by hard particles that are forced and moving along a solid surface, its action mechanism results from a combination of two steps that occur sequentially: the formation of grooves resulting from the abrasive grit pressing against the target body; the removal material in the front of the abrasive particles sliding on the surface of target body. Indeed, on the basis of this concept, some models postulate that the volume removed by hard particles for a given sliding distance is proportional to the groove volume formed by the particles in the relative motion [1-3].

The abrasive wear phenomenon is strongly felt for materials with poor wear resistance as the epoxy resin, widely used to fabricate high performance composite materials. In fact, the abrasion involves the tearing away of small pieces of materials. Particularly the tensile strength and hardness are important factors that determine the wear characteristics of a polymer [4]. Indeed, many researches are focused on the study of a relationship between the mechanical properties of the polymeric materials and their wear resistance; for example, Atkins [5] indicated that both in metals and polymers the dependence of the abrasive wear from the elastic modulus, the material fracture, toughness and the yield strength.

To overcome the disadvantage of poor wear resistance, many researchers made attempts in order to increase this performance by introducing various reinforcing agents and fillers including a variety of inorganic nanoparticles [6- 7]. Other researchers studied the wear of silica-filled epoxy resin composites: Xing and Li [8] used nanometer particles with a diameter of 120 and 510 nm while Durand et al. [9] used particles with size from 5 to 100 ◎ m; both focused on the effect of particle size on the wear behavior of nanocomposites at low levels of filler content and noted an increase of the resistance wear. Durand noted that the wear resistance increases with the particles size; the opposite was highlighted by Xing. This apparent inconsistency can be explained considering that the conditions of the tests used by the two researchers were very different. In particular, Durand used a normal load of 10 N with a very high specific pressure of 100-125 MPa while Xing used values of normal load of 1 and 2 N. In these tests, very different conditions for abrasive wear were realized. In fact, in the first case, the high contact pressure causes micro-cracking and micro-cutting mechanisms while, in the second one, conditions of adhesive wear due to the limited value of the applied load occurred. Indeed, the influences of the load on the abrasive wear properties was investigated by Koh et al. [10] and Kanchanomai et al. [11] using silica-filled epoxy resin composites.

In particular, in abrasive wear tests of reinforced polymer, as the contact pressure increases different mechanisms are evident, such as plowing, cracking and cutting [12-13]. In the plowing mechanism, abrasive particles plow the matrix and the reinforcement, alternatively, forming stress fields around them; compressive stresses are created in front and tensile stresses behind the abrasive particle. In the cracking mechanism, the motion of the abrasive medium leads the crack propagation along the interface between the matrix and the reinforcement. The cutting mechanism, present when matrix/reinforcement interface is relatively “strong”, is characterized by chips generation due to the propagation of cracks in the reinforcement.

Some other researchers studied the effect on the wear resistance of polymeric materials filled with Silicon Carbide (SiC). Harsha and Tewari [14] investigated the abrasive wear behaviour of polyaryletherketone (PAEK) and its composites against Silicon Carbide (SiC) abrasive paper; various mechanical properties such as hardness, ultimate tensile strength and elongation at break were analyzed for investigating wear property correlations. They concluded that the applied load, the sliding distance and the abrasive grit size have a significant influence on abrasive wear performance.

Suresha et al. [15] selected SiC particles and glass fiber to modify the epoxy resin and then to make SiC-glass fiber/epoxy composites with greatly improved mechanical strength and wear resistance in dry sliding conditions.

In this work, the results of a study using hard particles of Silicon Carbide (SiC) with microscopic dimensions (from 1.5 to 9 μm) are shown, deepening a previous work [16] in terms of abrasive wear realized with the use of an abrasive paper, in order to enhance the effect of hard material particles as filler of epoxy resin matrices. Since pin on disc is one of the most common tribological tests, because it allows to evaluate the friction coefficient and wear rates under variable sliding conditions [17], abrasive tests were carried out through a pin on disc apparatus, at low values of the applied load and adopting, as counterface, abrasive papers with different roughness values.

EXPERIMENTAL TESTS

Wear behaviour of unfilled and filled Mates SX10 epoxy resin was evaluated by means of two-body abrasive wear tests. They were carried out by a pin on disc apparatus; in these tests, the specimen slides on the surface of an abrasive paper, which is glued on the disc. The specimens were cut from plates of unfilled and filled epoxy resin; the filled ones were realized by mixing the resin and SiC powder on the ratios 100:30 and 100:10. Three different average particle sizes were employed, i.e. with radii of 1.5, 5 and 9 μm (which correspond to a mesh size of, respectively, 2000, 1000 and 600 grit). The plates were cured in a metallic mould at a temperature of 30°C for 24 hours. Three square specimens, with a side of 10 mm, were cut for each type of sample.

Sheets of SiC abrasive papers with different mesh sizes were employed; in detail, 280, 400 and 600 grit were chosen. The average roughness (R_a) of these abrasive papers was measured by a Taylor-Hobson rugosimeter; the values are reported in Table 1.

Each test was performed for a sliding distance of 1.7 m by three circular concentric paths, in order to always abrade the specimens with a new abrasive counterface. This distance was covered at a speed of 1 m/s and under two normal load conditions, i.e. 10 and 30 N. For these loads, the contact pressure (i.e. the ratio of the normal load to the specimen/counterface contact area) was of, respectively, 0.1 and 0.3 MPa.

Both cumulative mass and volume loss at the end of the tests were considered for evaluating the wear. Mass loss was given by the mass difference between the specimen before and after testing, using a precision balance with a sensitivity of 1 mg. The volume loss was measured dividing the mass loss by the density (equal to 1.11 g/cm^3 for the resin and, respectively, 1.29 and 1.58 g/cm^3, for the 100:10 and 100:30 composites). Figure 1 shows the execution of an abrasion test.

TABLE 1. Average roughness of different

Mesh size (grit)	R_a (μm)
280	15.93
400	11.04
600	9.28

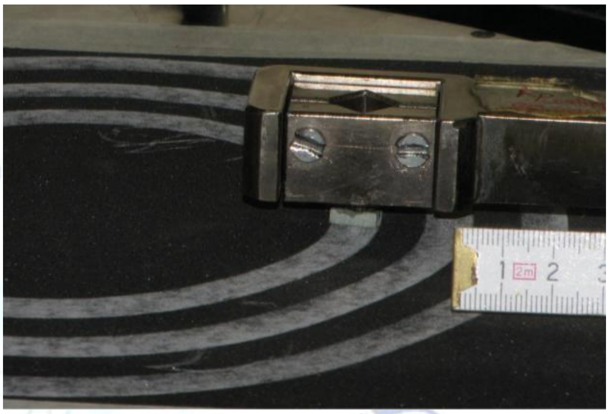

FIGURE 1. Abrasion test

RESULTS

The mean results of the tests for all the different parameter combinations are reported in Table 2, where it is possible to highlight that the wear increases with the load, and then with the pressure, and when passing from the finer to the coarser paper. The higher wear resistance is obtained by the composite resin with the resin-to-filler ratio of 100:30 and the powder with a mesh size of 600; the lower one among the composites is obtained with the resin- to-filler ratio of 100:10 and the powder with a mesh size of 2000.

Table 3 reports the percentage reduction of volume loss, $\%\Delta Vol_{Red}$. This feature measures the variation of wear resistance of the composite resin samples compared with the ones of only resin, under the same work conditions (contact pressure and counterface). It is evaluated by the following formula:

$$\%\Delta Vol_{Red} = \frac{\Delta VolR - \Delta VolC}{\Delta VolR} \cdot 100$$

where ΔVol_R and ΔVol_C are, respectively, the volume loss of resin and composite resin for each considered combination of load and abrasive paper.

TABLE 2. Volume loss

Sample	Particles size (grit)	Load (N)	Volume loss (mm³) Abrasive paper mesh size (grit)		
			280	400	600
Resin		10	24.5	20.0	15.5
		30	50.0	34.0	29.1
Composite 100:10	600	10	10.9	5.4	3.9
		30	24.0	10.1	7.0
	1000	10	16.3	8.5	7.8
		30	31.0	17.1	13.2
	2000	10	19.4	12.4	8.5
		30	39.5	24.8	16.3
Composite 100:30	600	10	6.3	3.8	3.2
		30	15.8	7.6	5.1
	1000	10	12.0	5.1	3.8
		30	24.7	10.1	7.6
	2000	10	17.7	10.8	7.0
		30	38.6	19.6	13.9

TABLE 3. Percentage of volume loss reduction

Sample	Particles size (grit)	Load (N)	$\%\Delta Vol_{Red}$(%) Abrasive paper mesh size (grit)		
			280	400	600
Composite 100:10	600	10	55.8	72.9	74.9
		30	51.9	70.4	76.0
	1000	10	33.7	57.4	49.8
		30	38.0	49.8	54.7
	2000	10	21.0	38.0	44.8
		30	20.9	27.0	44.0
	600	10	74.2	81.0	79.5
		30	68.4	77.7	82.6
Composite 100:30	1000	10	51.0	74.7	75.4
		30	50.6	70.2	73.9
	2000	10	27.8	46.2	55.0
		30	22.8	42.73	52.1

Table 3 highlight an improvement of the wear behaviour for each test, since all the measured values are positive. Moreover, the wear resistance strongly depends on the investigated parameters; in fact, $\%\Delta Vol_{Red}$ varies from 20.9 to 82.6%.

In order to understand the influence of the different parameters, some significant cases are reported in Figures 2- 4; the first one shows the wear versus load for the most abrasive counterface (280 grit abrasive paper), whereas Figures 3 and 4 show the wear versus, respectively, the counterface average roughness and the filler particles size for the highest load and filler content values. From Figure 2, an improvement of wear resistance is shown for the composite resins with both the filler content and the particles size; moreover, the wear increases more than linearly with the counterface roughness (Figure 3) and decreases less than linearly with the particles size (Figure 4).

Let us consider the 9 cases represented in Figures 3 and 4, related to the composite resins with the highest filler content, that is the most performing, under the worst load condition; Table 3 highlights an improvement that varies from 22.8% for the composite with the finest particles against the coarser counterface to 82.6% for the one with the coarsest particles against the finest counterface.

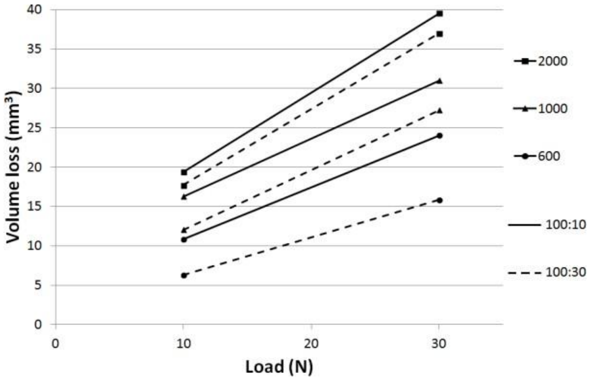

FIGURE 2. Wear versus load (280 grit abrasive paper)

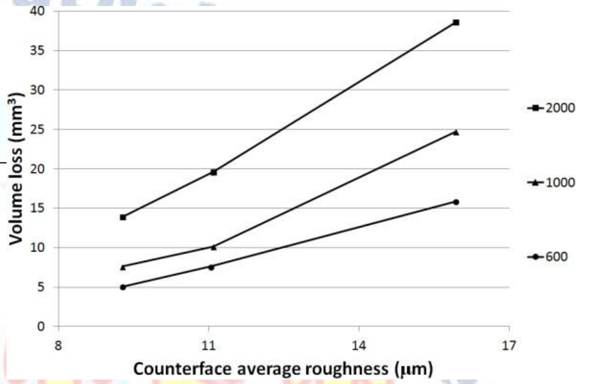

FIGURE 3. Wear versus counterface average roughness (load of 30 N; resin-to-filler ratio of 100:30)

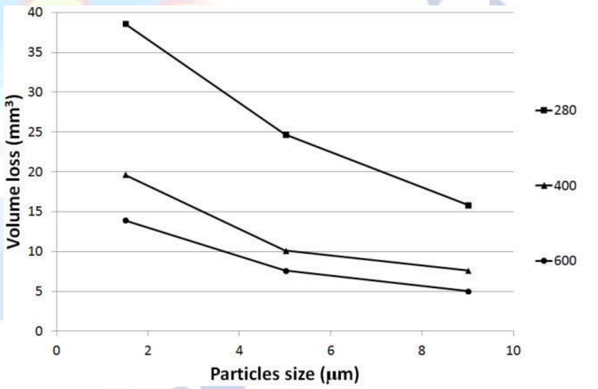

FIGURE 4. Wear versus filler particles size (load of 30 N; resin-to-filler ratio of 100:30)

CONCLUSIONS

In the present work, the possibility of increasing the abrasive wear of thermoset polymers was evaluated by filling the epoxy resin with hard powder of SiC. The filling was realized with both different content and particle sizes.

From sliding tests resulted that the wear resistance increases with both the content and the dimensions of the filling particles. In particular, the wear increases with the contact pressure and more than linearly with the roughness of the counterface.

Starting from these considerations and extending the experimental campaign to better understand the influence of the different parameters, a future work will consider the elaboration of an analytical formula to determine the wear as a function of the particles size, the filler content, the roughness of the counterface and the applied load

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