A Study on Mechanical and Wear Characteristics of Epoxy Filled with Borosilicate Glass Micro-spheres

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Abstract: ***This article reports on the modified mechanical and dry sliding wear characteristics of epoxy matrix composites filled with borosilicate glass micro-spheres (BGMs). Composites with four different compositions (epoxy filled with 0, 10, 20, 30 wt% of BGM) are prepared by simple hand lay-up technique. Physical characterizations of these composites are done and it is seen that incorporation of BGM modifies the density, porosity and bulk hardness of the composites. Dry sliding wear trials are then conducted using a pin-on-disc set up as per ASTM G-99 test standards. A well planned experimental schedule based on Taguchi's L_{16} model is followed. Significant control factors affecting the wear characteristics are identified. This work shows that BGMs possess good filler characteristics as far as the wear resistance of thermoset polymer like epoxy resin is concerned.***

Keywords: Epoxy, Polymer Composite, Borosilicate glass micro-spheres, Characterization, Wear

1. Introduction

It has been observed that by incorporating hard filler particles into polymer based composites, synergistic effects may be achieved in the form of higher modulus and reduced material cost [1–3]. The improved performance of polymers and their composites in industrial and structural applications by the addition of particulate fillers has shown a great promise and so has lately been the subject of considerable interest. The inclusion of such particulate fillers into polymers for commercial applications is primarily aimed at the cost reduction and stiffness improvement [4, 5]. There is a large no. of references available those suggest a large number of materials being used as fillers in polymers [6–9]. Ceramic particle filled polymer composites have also been the subject of extensive research in recent years and consequently a number of reports are available on the use of ceramics such as Al_2O_3, SiC etc. as particulate fillers [10-13].

The potential of borosilicate glass micro-spheres (BGM) as a filler material in polyester matrix has not been reported so far. In the present study, borosilicate glass micro-spheres (BGM) particles of average size 100 μm are reinforced in unsaturated polyester resin to prepare particulate filled composites of four different compositions (with 0, 5, 10, 15 wt % of BGM). Dry sliding wear trials are conducted following Taguchi's technique using a standard pin-on-disc test set-up. Significant control factors predominantly influencing the wear rate are identified. Borosilicate glass is mainly composed of silica SiO_2 (70-80%), boron oxide B_2O_3 (7-13%) and smaller amounts of the alkalis (sodium and potassium oxides) such as 4-8% of Na_2O and K_2O, and 2-7% aluminum oxide (Al_2O_3). Boron gives greater resistance to thermal changes and chemical corrosion. Borosilicate glass has excellent thermal properties with its low coefficient of expansion and high softening point; it also offers a high level of resistance to attack from water, acids, salt solutions, organic solvents and halogens..

2. Experimental details

Density and void fraction

The theoretical density of composite materials in terms of weight fraction can easily be obtained as for the following equations given by [14]

$$\rho_{ct} = \frac{1}{(W_f/\rho_f)+(W_m/\rho_m)} \tag{1}$$

Where, W and ρ represent the weight fraction and density respectively. The suffix *f*, *m* and *ct* stand for the filler, matrix and the composite materials respectively. The actual density (ρ_{ce}) of the composite, however, can be determined experimentally by simple water immersion technique. The volume fraction of voids (V_v) in the composites is calculated using the following equation

$$V_v = \frac{\rho_{ct} - \rho_{ce}}{\rho_{ct}} \tag{2}$$

Micro-Hardness

A Leco micro hardness tester is used for measurement of micro hardness. A diamond indenter, in the form of a right pyramid with a square base and an angle 136^0 between opposite faces has been used in this tester. This indenter is forced into the material under a load F. In the present study, the load considered F = 0.5N. The indentation left on the surface of the material after removal of the load has two diagonals X and Y. These diagonals are measured and their arithmetic mean L is calculated. The Vickers hardness number is calculated using the following equation

$$H_v = 0.1889\frac{F}{L^2} \tag{3}$$

$$L = \frac{X+Y}{2}$$

Where F is the applied load (N), L is the diagonal of square impression (mm), X is the horizontal length (mm) and Y is the vertical length (mm).

Sliding Wear Test

To evaluate the performance of these composites under dry sliding condition, wear tests are carried out in a pin-on-disc type friction and wear monitoring test rig (supplied by DUCOM) as per ASTM G 99. The counter body is a disc made of hardened ground steel (EN-32, hardness 72 HRC, surface roughness 0.6 lm Ra). The specimen is held stationary and the disc is rotated while a normal force is applied through a lever mechanism. A series of tests are conducted with four different sliding velocities under four different normal loadings. The material loss from the composite surface is measured using a precision electronic balance with accuracy ±0.1 mg and the specific wear rate (mm^3/N-m) is then expressed on 'volume loss' basis as:

$$\mathbf{W_s = \Delta m / (\rho t V_s F_n)} \quad \mathbf{(4)}$$

where Dm is the mass loss in the test duration (g), q is the composite (g/mm^3), t is the test duration (s), Vs is the sliding velocity (m/s), and Fn is the average normal load (N). The specific density density of the wear rate is defined as the volume loss of the specimen per unit sliding distance per unit applied normal load

Table 1: Specific wear rates obtained for different test conditions with S/N ratios

Sliding velocity A (cm/sec)	Normal load B (N)	Sliding distance C (m)	BGM content D (wt %)	Sp. wear rate Ws (10^{-5} mm^3/N-m)	Signal-to-noise Ratio (db)
105	5	1000	0	0.489	6.2138
105	15	1500	10	0.360	8.8739
105	25	2000	20	0.289	10.7820
105	35	2500	30	0.208	13.6387
209	5	1500	20	0.523	5.6300
209	15	1000	30	0.493	6.1431
209	25	2500	0	0.798	1.9599
209	35	2000	10	0.632	3.9857
314	5	2000	30	0.584	4.6717
314	15	2500	20	0.736	2.6624
314	25	1000	10	0.957	0.3818
314	35	1500	0	1.175	-1.4008
420	5	2500	10	1.657	-4.3865
420	15	2000	0	1.812	-5.1632
420	25	1500	30	1.067	-0.5633
420	35	1000	20	1.398	-2.9101

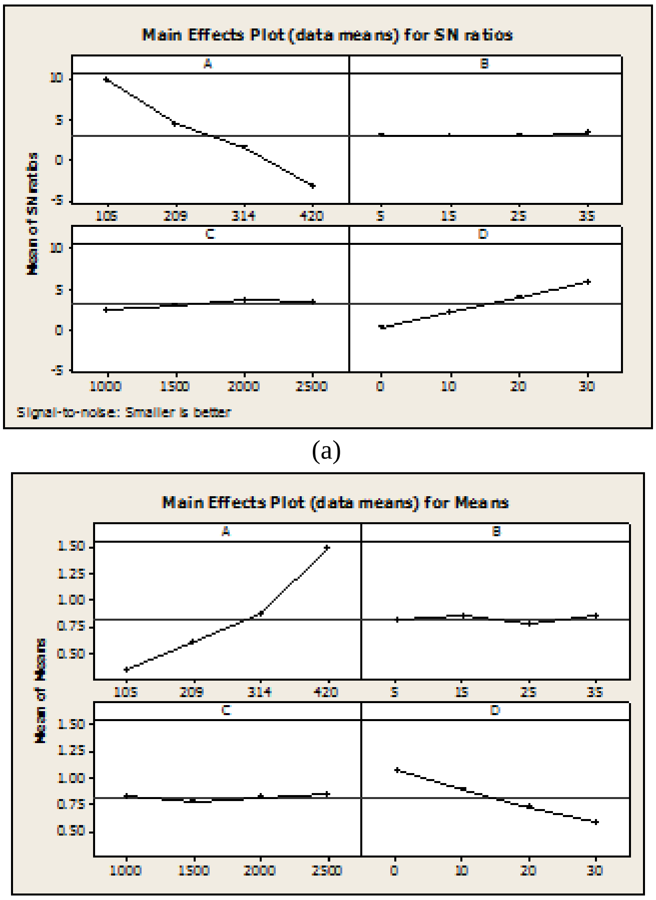
3. Results and Discussion

Mechanical characterization

With inclusion of BGM particles in the epoxy matrix the density of the composite is found to be increasing. The improvement in density is obvious as the true density of BGM is little higher than that of neat epoxy. The composite micro-hardness is also found to be enhanced many fold as the BGM content in the matrix increases from 0 to 30 wt%.

Dry sliding wear test results

The specific wear rates obtained for all the 16 test runs for the set of composites along with the corresponding signal to noise (S/N) ratios are presented in Table 1. From this table, the overall mean of the S/N ratios is found to be 3.1574 db. This is done using the software MINITAB 14 specifically used for design of experiment applications. The S/N ratio response analysis shows that among all the factors, sliding velocity (A) is the most significant factor followed by BGM content (D) while the normal load and sliding distance have relatively very less significance on wear rate of these glass micro-sphere filled composites under this investigation.



(a)

(b)

Figure 1 Effect of control factors on wear rate

Table 2 Response Table for Signal to Noise Ratios (Smaller is better)

Level	A	B	C	D
1	9.8771	3.0323	2.4571	0.4025
2	4.4297	3.1291	3.1350	2.2137
3	1.5788	3.1401	3.5691	4.0411
4	-3.2558	3.3284	3.4687	5.9726
Delta	13.1329	0.2961	1.1119	5.5701
Rank	1	4	3	2

The analysis of the results leads to the conclusion that factor combination of A_1, B_3, C_3 and D_4 gives the minimum specific wear rate in this case (Figures 1a and 1b). The response table for S/N ratio for these is shown in Table 2

4. Conclusions

This experimental investigation into the sliding wear behavior of BGM filled epoxy matrix composites leads to the following conclusions:

1. Solid borosilicate glass microspheres can be used as a potential filler material in epoxy matrix composites. Incorporation of BGMs modifies the physical and mechanical characteristics of these composites.
2. Dry sliding wear characteristics of these composites can be successfully analyzed using Taguchi experimental design scheme. The Taguchi method provides a simple, systematic, and efficient methodology for the optimization of the control factors.
3. Factors like sliding velocity, BGM content are found to be significant to minimize the specific wear rate.

BGMs are found to possess good filler characteristics as they improve wear resistance of the composite

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