Study of mechanical and Wear behavior of carbon fiber reinforced epoxy resin composites with alumina filler additions

[1] Devaraj.Eand [2] Haseebuddin.M.R
[1]Department of Mechanical Engineering, UVCE, Bangalore, India
[2]Faculty, Department of Mechanical Engineering, DSCE, Bangalore, India

Abstract

This paper describes the fabrication and testing of carbon fiber reinforcement epoxy resin composites with alumina filler added to the matrix. Carbon fiber reinforced epoxy composites without fillers and with 2%, 4% and 6% filler additions are fabricated. The resulting composites cast were tested for their strength, hardness and wear resistance. Strength increase by up to 4% of filler addition and hardness is increase by up to 2% of filler additions and highly dependent on the location of the casting from where the test specimens are taken. In three body wear behavior,the main intension was to increase the wear resistance using alumina filler content and it was observed that wear decreased with increasing filler content. In two body wear behavior also indicates that wear resistance has improved in composites with filler up to 4%.

Key Words: Fillers, Tensile test, Carbon fiber, Epoxy.

1. Introduction

Composite materials are engineered material made from two or more constituent materials with significantly different physical or chemical properties and which remain separate and distinct on a macroscopic level within the finished structure.

Polymer composites are promising in tribological and mechanical applications due to the possibility of tailoring their properties with special fillers such as MoS_2, CuO, CuS, Al_2O_3, graphite, tungsten carbide, tantalum, niobium, bronze and silicon carbide (SiC).

Thermoset epoxy resins [1] are extensively studied as a matrix material for composite structures as well as adhesives for space and aerospace applications because they exhibits low shrinkage, higher mechanical properties, easy fabrication, excellent chemical and moisture resistance, good wettabality and good electrical characteristics

The studies covers the tribological behaviour and the mechanical behaviour of the carbon fiber reinforced epoxy composite filled with alumina additives of different percentages Many researchers have studied the abrasive wear behaviour of polymer composites . Silicon carbide and alumina can significantly improve the flexural modulus and wear resistance of the epoxy composites. Various researchers have reported that the wear resistance of polymers is improved by the addition of fillers such as mica, talc, calcium carbonate, feldspar, graphite, MoS_2, CuO, CuS, Al_2O_3 etc. The carbon fiber/epoxy resin systems are fabricated with alumina filler and without alumina filler using and hand lay-up technique.

1.1 Materials and Methods

Epoxy as a matrix material and carbon Fiber as reinforcement was obtained from “Syntax Fiber”, Bangalore. The LY 556 is a clear liquid resin, with density 1.28g/cm³. The hardener HY 951 [2] is a liquid with its density 0.94g/cm³. The commercially available alumina powder of density 3.9g/cm³ was obtained from “The Mysore Pure Chemicals”, Mysore. Its mesh size ranged from 70-100 was used as filler material. The films were prepared by the hand lay-up technique on the rectangular box. The laminate is cured under light pressure for 2 hrs, followed by curing at room temperature for 24 hrs. The tensile test was conducted using Hounstill’s universal testing machine to study the tensile properties. The Test were conducted in according to ASTM D-638. Hardness test were conducted using shore Durometer according to ASTM D-2240.The three body abrasive wear behavior are studied using rubber wheel abrasion test *(RWAF)* apparatus and The two body abrasive wear behaviour was studied using pin on disc apparatus.

2. Experimental Study

Wear is defined as damage to a solid surface, generally involving progressive loss of material, due to relative motion between that surface and contacting substance or substances. The five main types of wear are abrasive, adhesive, fretting, erosion and fatigue wear, which are commonly observed in practical situations. Abrasive wear [3] is the most important among all the forms of wear because it contributes almost 63% of the total cost of wear. Abrasive wear is caused due to hard particles or hard protuberances that are forced against and move along a solid surface.

2.1 Pin on disc test procedure

Figure 1.Pin-On-Disc Apparatus

Two-body abrasive wear test was conducted by using a pin-on-disc machine as per ASTM-G99. Figure1 shows the two body wear mechanism. The surface of the sample (10mm×10mm) glued to a pin of dimensions 10 mm diameter and 25 mm length, which comes in contact with the surface of the disc. Wear monitor (DUCOM; TL-20) with data acquisition system [4]. The disc rotates with the help of a D.C. motor; having speed range 0-2000 rev/min with wear track diameter 50 mm-200 mm, which could yield sliding speed 0 to 10 m/sec. Load is to be applied on pin (specimen) by dead weight through pulley string arrangement. The system has a maximum loading capacity of 200N.

2.2 Three body wear test procedure

Figure 2.Three Body Abrasion Tester

Figure 2(a). Specimen before and after test

Three-body abrasive wear studies were carried out on a dry sand/ RWAT rig as shown in figure 2.The abrasives are introduced between the test specimen and the rotating wheel with a chlorobutyl rubber tire [5]. The test specimen is pressed against the rotating wheel at a specified force by means of lever arm while a controlled flow of grit abrades the test surface. The rotation of wheel is such that its contact face moves in the direction of grit flow. The pivot axis of the lever arm lies within a plane, which is approximately tangential to the rubber wheel surface and normal to the horizontal diameter along which the load is applied. The tests were carried out for different loads of 23N and 32N and sliding distances varied in step from 150m to 600m. The rubber wheel was rotating at a speed of 200rpm .An abrasive particle used was silica was of ASF grade 60 and were angular in shape with sharp edges. Sand flow rate between rubber wheel and specimen was 250 ± 5 g/min .The size of the specimen was 75mm x 25mm x 2.5mm as shown in fig 2(a). Weight loss measurements were made at regular test intervals of 60 s using an analytical balance reading to 1 x 10^{-5}g. 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.

3. Tensile test study

A tensile test also known as tension test is probably the most fundamental type of mechanical test we can perform on a material. Tensile tests [6] are simple, relatively inexpensive, and fully standardized. Tensile test was conducted on specimens cut from fabricated composites with filled and unfilled filler. By pulling a specimen we can find its tensile strength by measuring its deformation. As we continue to pull on the material until it breaks, we will obtain a good, complete tensile profile. A curve will result showing how it reacted to the forces being applied. The point of failure is of much interest and is typically called its Ultimate Strength or UTS on the chart. Ultimate strength is calculated based on gross cross sectional area.

Figure 3.Tensile Testing Machine UTM.

Figure 4.Specimen before and after test

4. Hardness test

The test determines the indentation hardness of the fabricated specimen .It is done with the help of Shore Durometer [7,8]. A Durometer is an instrument that is commonly used for measuring the indentation hardness of rubbers/elastomers and soft plastics such as polyolefin, fluoropolymer, and vinyl.

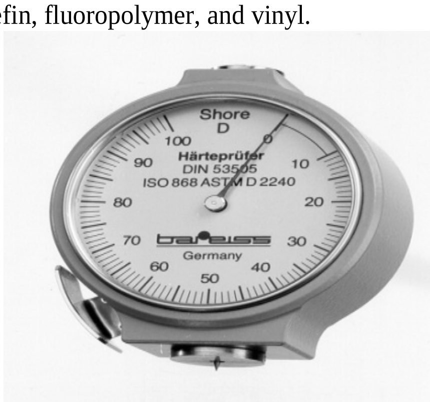

Figure 5.Shore Durometer

5. Results

5.1 Tensile test

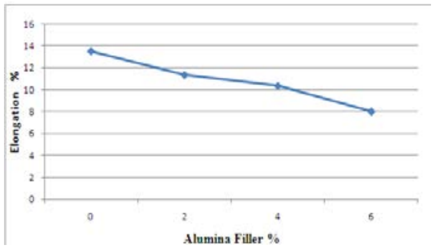

Figure 6.Percentage elongation as a function of alumina filler content

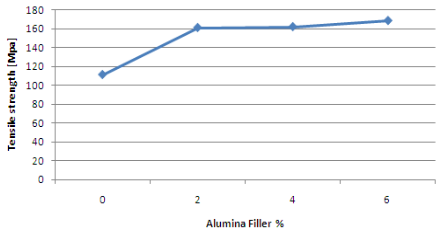

Figure 7.Tensile strength as a function of alumina filler content

It is observed that, the carbon fiber reinforced epoxy composites without alumina filler has highest percentage of elongation of 13.49 % and carbon fiber reinforced epoxy composite with 6% of alumina filler the elongation percentage is decreased to 8%. The tensile strength of the composite without filler and with 2% ,4% and 6% of the alumina content has been increased from 111.426 MPa,161.55 MPa ,162.48MPa and 168.99 MPa.

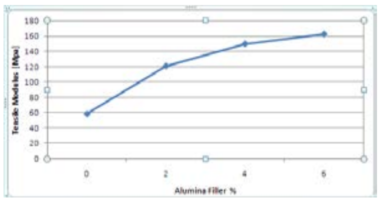

Figure 8.Tensile modulus as a function of alumina filler content

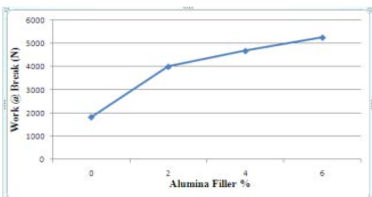

Figure 9.Work at break as a function of alumina filler content

The composite, having higher filler content shows the higher tensile modulus than the carbon fiber

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reinforced epoxy composite without filler addition. For the increase in alumina content the work at break is increased from 1822.75N ,4000.8N, 4685.33N, 5265N for carbon fiber reinforced epoxy composite without filler and composite with 2% ,4% and 6% of filler addition .This indicates that the composites property changes from ductile to tough and rigid, due to addition of Al_2O_3 particles in carbon fiber reinforced epoxy composite.

5.2 Two body wear test

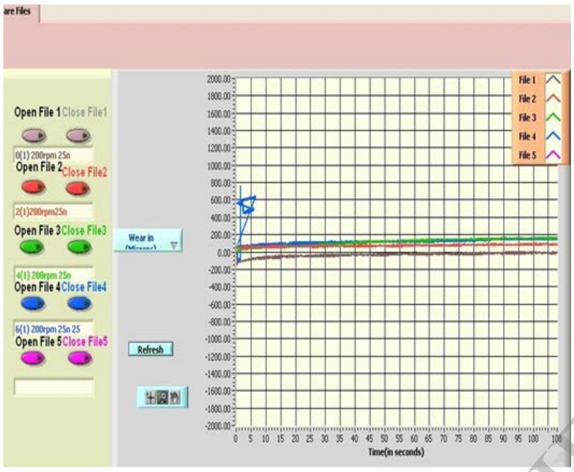

Figure 10.Wear of the polymer composite against time at load 25n for 200rpm

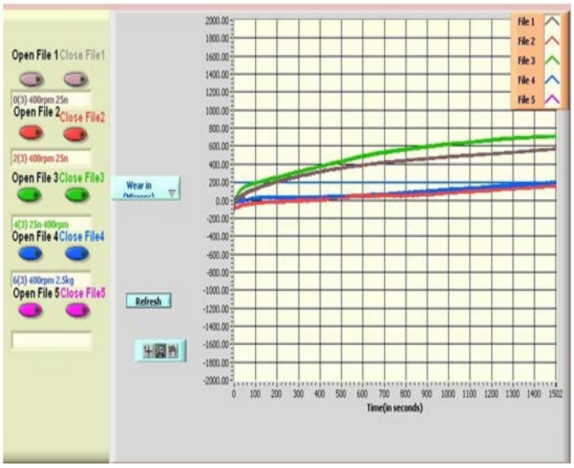

Figure 11.Wear of the polymer composite against time at load 25n for 400rpm

In the present study figure 10 and figure 11 shows the linear increase in wear loss with increase in sliding distance, load and time in seconds. From both the fig it is observed that the wear loss is increased with increase in speed i.e. from 200rpm to 400rpm at load 25 N. Carbon fiber reinforced epoxy composite with 4% alumina filler shows higher wear than carbon fiber reinforced epoxy composite with 2% and 6% of filler addition. For high value of the normal load the wear loss has been reduced compared to that of wear loss in low normal load.

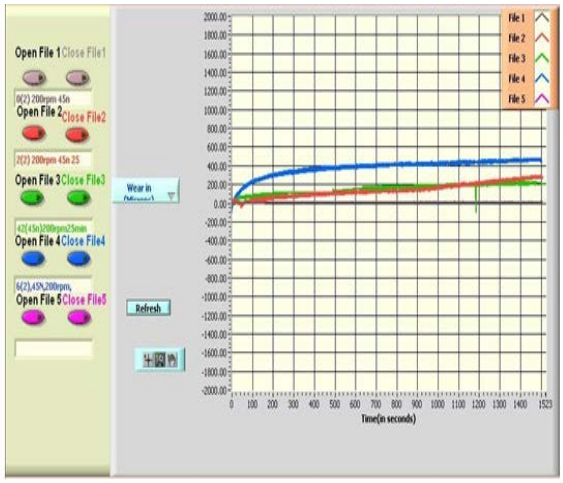

Figure 12.Wear of the polymer composite against time at load 45n for 200rpm

Figure 13.Wear of the polymer composite against time at load 45n for 400rpm

Also from figure 12 and figure 13 shows that the Carbon fiber reinforced epoxy with 4%wt of alumina filler at load 45N and speed 400rpm, has been reduced in wear loss. As further increase in filler content of 6% in carbon fiber reinforced epoxy composite, wear loss has increased steadily.A polymeric film was deposited on the steel counterface; in fact the wear debris, generated by the ploughing effect of the asperities of the steel disk, covers the sliding path and is compacted on the steel disk.

5.3 Three body wear test

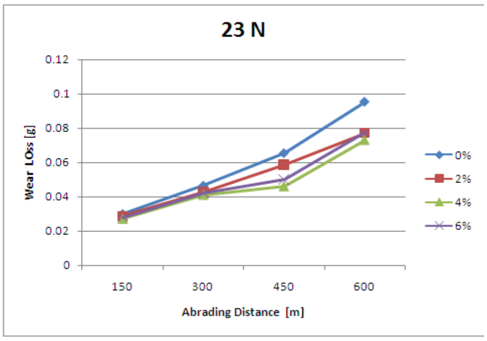

Figure 14.Wear loss Vs Abrading distance at load 23N.

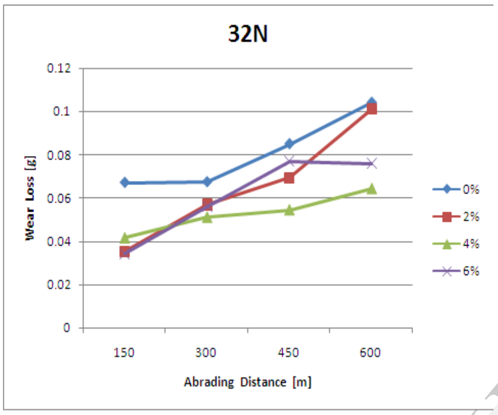

Figure 15.Wear loss Vs Abrading distance at load 32N.

It is observed in fig figure 14 that wear loss is increasing with the increase in abrading distance and wear loss has been decreased with increase in alumina filler addition. Carbon fiber reinforced epoxy composite without alumina filler shows greater increase in the wear loss of 0.095g for the abrading distance of 600m and load 23N. Carbon fiber reinforced with epoxy composite of 4% alumina additives results in lesser wear loss of 0.077g compared with that of composite without alumina additives.

Table 1: Values of Wear Loss (g) At 23N

	150	300	450	600
CF/Epoxy	0.03	0.0465	0.0655	0.0955
CF/Epoxy/ 2% Filler	0.029	0.043	0.0588	0.07719
CF/Epoxy/ 4% Filler	0.027	0.041	0.046	0.07289
CF/Epoxy/ 6% Filler	0.028	0.042	0.05	0.07725

Table 2: Values of Wear Loss (g) At 32N

	150	300	450	600
CF/Epoxy	0.067	0.0673	0.0849	0.104
CF/Epoxy/ 2% Filler	0.0355	0.057	0.0694	0.101
CF/Epoxy/ 4% Filler	0.0416	0.0511	0.0545	0.0643
CF/Epoxy/ 6% Filler	0.0342	0.056	0.0771	0.076

It is also observed that the wear loss has been dropped as the load increased i.e. In figure 15 for the load 32N and sliding distance of 600m the laminate with 4% of alumina filler shows 0.065g of wear loss. The wear loss effect due to this phenomenon increases with increase in content of fillers. Further increase in alumina content there is a increase in wear property due to the poor interaction of epoxy resin with alumina filler. There by it is seen that the Carbon fiber reinforced epoxy composite with 4% of alumina filler shows the better wear behaviour than carbon fiber reinforced epoxy with, 2% and 6% of alumina filled carbon fiber reinforced epoxy composite

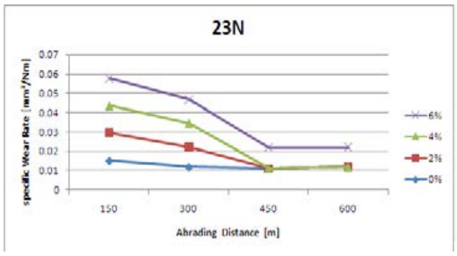

Figure 16.Specific wear rate Vs Abrading distance at load 23N.

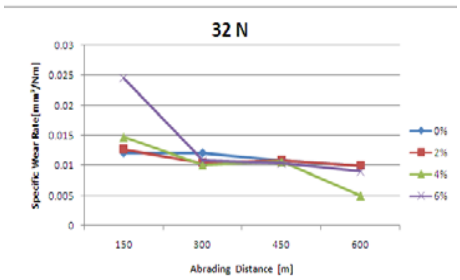

Figure 17.Specific wear rate Vs Abrading distance at load 32N.

Figure 16 and figure 17 shows specific wear rate as a function of abrading distance, indicates that the wear rate drops linearly with increase in abrading distance.Also it resulted in indicating as the filler content increased in laminate the specific wear rate has been reduced up to the 4% of filler addition. The highest specific wear rate is shown for carbon fiber reinforced epoxy with 6% of alumina with 0.0144 mm^3/Nm at load 23N for 150m. As load increased the specific wear rate has been increased with increase in alumina content and sudden drop for 4% of alumina content at load 32N for sliding distance of 600m.

5.4 Hardness test

Table 3: Values of shore D hardness

Composition	Shore D hardness
CF-Epoxy resin	82
CF-Epoxy resin +2% Allumina	87
CF-Epoxy resin +4% Allumina	84
CF-Epoxy resin+6% Allumina	82

The measured hardness test results of unfilled and alumina filler enriched epoxy resin composites are shown in table 3. The surface hardness of alumina filled epoxy resin is highest for 2 % alumina carbon fiber/polymer composite. With increase in proportion of alumina the shore D hardness has comparatively decreased.

6. Conclusions

The following conclusions can be made from the paper:

Mechanical tests:

- The specimen with 4% alumina filler content display better tensile characteristic.
- The highest surface hardness was observed in the specimen with 2% filler content.

Three body wear

- It was observed that specimen with higher content of filler displayed good wear resistance .
- The wear rate decreased with increasing filler content up to 4% and slightly decreased at 6 %.

Two body wear

- Two body wear behavior indicates wear resistance has improved in composites with fillers up to 4% and then subsequently decreased.

7. Further study

- Composites with higher filler content 8%, 10%. etc can be fabricated and mechanical and wear behavior can be evaluated, also flexural analysis and surface morphology can be carried to study mechanical and wear behavior of different composites using SEM.
- Composites with varied content of carbon fibers can also be fabricated and tested for studying the mechanical and tribological properties. Also wear test can be carried out for higher loading and sliding distances.

8. References

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