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Tribological Characteristics of Carbon-Epoxy with Ceramic Particles Composites for Centrifugal Pump Bearing Application

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Abstract: In this research, the investigation was aimed to develop plain journal bearing with better wear resistance. The Carbon-epoxy composite with addition of different fillers in different weight fractions were fabricated. The fillers such as silicon carbide and aluminum oxide were used as secondary reinforcement and fabricated using vacuum bag molding technique. The mechanical properties were evaluated using Universal testing machine and Brinell hardness testing machine as per ASTM standards. The wear behaviors were evaluated using pin-on-disc apparatus with different loads. Better mechanical properties and wear properties were obtained with increase in weight percentage of secondary reinforcement content. Further it was found that carbon-epoxy with 10 % SiC and 5 % Al_2O_3 exhibited better wear resistance and better strength which can be used for bearing application. The Plain journal bearing with better strength and wear resistance was fabricated and tested in centrifugal pump.
Keywords: - Polymer composite, Hardness, Compressive strength, Wear

1. Introduction

The fiber reinforced polymer composites are the most rapidly growing class of materials, due to their good combination of high specific strength and modulus. They are widely used in variety of engineering and automobile applications. In recent years, there have been rapid growth in the Development and application of fiber reinforced thermosetting polymer composites such as epoxy, polyester and vinyl ester. This is due to the realization of their good strength, low density and high performance to cost ratio with rapid clean processing. In recent times, there has been a remarkable growth in the large-scale production of fiber and/or filler reinforced epoxy matrix composites. Because of their high strength-to- weight and stiffness-to-weight ratios, they are extensively used for a wide variety of structural applications as in aerospace, automotive and chemical industries. On account of their good combination of properties, fiber reinforced polymer composites (FRPCs) are used for producing a number of mechanical components such as gears, cams, wheels, brakes, clutches, bearings and seals [1]. Most of these are subjected to tribiological loading conditions. Various researchers have studied the tribiological behavior of FRPCs. Studies have been conducted with various shapes, sizes, types and compositions of fibers in a number of matrices. Many investigations have been done on wear properties on polymer composites. B. Suresha et al (2010) studied the tribiological properties of vinyl ester based composites with two different fibers such as carbon and glass fibers. They conclude that friction and wear characteristics of bidirectional fabric reinforced vinyl ester composites depends on the fabric materials. Carbon-vinyl ester composites showed lower friction under different loads /sliding velocities and hence may be suitable for bearing applications. The wear resistance is improved with addition of carbon fiber in vinyl ester than glass fiber. In recent years, many researchers have been devoted to explore the potential advantage of thermoses matrix for composites applications [2]. G. Chandramohan et al (2008) studied the wear behavior of vinyl ester based composite with the addition of different fillers such as SiC, graphite and glass fiber. Wear volume increases with increase in abrading distance/loads for all samples. They conclude that SiC filled glass-vinyl ester composites showed better wear resistance and wear rate is higher in unfilled glass fiber reinforced vinyl ester composites and graphite fillers are not very beneficial to the wear performance [3]. R. Prehn et al (2005) studied wear performances of polymer composites with different fillers. Epoxy resin with addition of fillers such as silicon carbide exhibits good wear properties which can be used for bearing applications [4]. Y.Z.Wan et al (2006) wear performances increased with addition of more percentage of fiber content in polymer composites. Carbon fiber has good tribiological and mechanical properties which increases the wear properties of the composites with specific wear rate and coefficient of friction gradually increases with increase in fiber volume content in composites [5]. B. Suresha et al (2009) investigated the dry sliding wear of carbon-epoxy with the addition of graphite fillers from 5 to 10%. They conclude that wear properties is improved with increase in graphite powder content in carbon-epoxy composites and further they conclude that 10% graphite carbon-epoxy exhibits high wear resistance compared to 5% and unfilled composites [6]. K.Gopala Krishna et al (2009) studied the friction and wear characteristics of polymer based composites with addition of steel powder and alumina powder. They conclude that addition of steel powder exhibits high wear rate compared to ceramic particles. Alumina is suitable for increasing wear performances. Polymer exhibits low friction coefficient compared to metals to their low interfacial adhesion energy. By reinforcing fillers such as metals, ceramics and fillers increase the strength and stiffness of the matrix [7]. H. Unal et al (2004) studied wear performances on PTFE composites with different fillers such as glass, carbon and bronze with different volume fractions. They conclude that addition of glass fiber, bronze and carbon fillers to PTFE were found effective in reducing the wear rate of the PTFE composites. Wear rates are little sensitive to test speed and large sensitivity to the applied loads particularly at high values [8]. Siddhartha et al (2012) studied the mechanical and tribiological properties of epoxy based composites with two different fiber forms bidirectional and chopped glass fiber. They conclude that bidirectional glass fiber exhibits good mechanical and tribiological properties compared to chopped fibers, because of bonding between the fibers and matrix [9]. Hui Zhang et al (2007) studied the influence of fiber length on tribiological properties and carbon fiber reinforced epoxy composites. They conclude that long carbon fibers exhibits better wear resistance than these with short carbon fibers in epoxy composites [10]. Osman Asi (2010) investigated the bearing strength of glass-epoxy composites with addition of $Al_2O_3$with different volume fractions. The increase of Al_2O_3particle loading in the matrix improved bearing strength of the composites. Further it is concluded that increase in Al_2O_3 more than 10% decreases the strength but remains above that of the unfilled glass reinforced epoxy composites [11]. B. Suresha et al (2006) investigated glass-epoxy with SiC as fillers. They conclude that silicon carbide filled glass-epoxy composites shows higher resistance to slide wear compared to plain glass-epoxy composites [12]. BekirSadik et al studied tribiological properties of polymer based journal bearing with different polymers such as PE, PA, POM, PTFE and Bakelite bearing. They conclude that higher wear resistance has been obtained in PA and POM bearings [13]. L. Wang et al (2000) compared conventional steel, silicon nitride material shown significant benefits in terms of rolling contact fatigue life and the lower density of the material greatly reduces the dynamic loading which can be used in high speed applications such as machine tool spindles and gas turbine engines. As a result of their sustained development and testing. It is expected that silicon nitride baking will be usedin all types of applications [14]. Guang Shi et al (2003) investigated friction and wear of low nanometer silicon nitride filled epoxy composites. They conclude that incorporation of nano-Si_3N_4 particle into epoxy can significantly reduce frictional coefficient and wear rate of the latter under dry sliding wear conditions [15]. Siddhartha et al (2011) conclude that the addition of Titania in epoxy composites exhibits high wear resistance and better mechanical properties and Zhenyu et al (2008) carbon fiber reinforced polyphenlylene with TiO_2 as fillers.Sandhyatani Biswas et al (2009) investigated the wear performances on red mud filled glass-epoxy composites. They conclude that hardness is improved with increase in red mud content and mechanical properties such as tensile; shear impact strength is decreased with increase in red mud particle content in glass-epoxy composites [16.17,18,]. Fibers reinforced polymer composites are used for producing number of mechanical components such as gears, cams, wheels, brakes, clutches, bush bearing and seals. Considerable efforts are being made to extend the range of applications.In aircraft and space vehicles high reliability and relatively long life are required of all assemblies and elements, including bearings. With the advent of the space era very demanding bearing operating conditions such as high vacuum, extreme temperatures, large temperature differentials, long life (both wear and fatigue life, usually 10–15 years without maintenance) and low frictional power are quite common. Use of inorganic fillers dispersed in polymeric composites is increasing. Fillers not only reduce the cost of the composites, but also meet performance requirements, which could not have been achieved by using reinforcement and resin ingredients alone. Pushkar Venkatesh Kulkarni et al (2012) fabricated and testing PTFE based composite bearing material for turbine pump with addition of different fillers in PTFE composites. They conclude that bronze filled with PTFE composite bearing exhibits good wear resistance [19].

2. Experimental Details

2.1 Materials

The materials such as carbon, epoxy resin and ceramic particles were used. Epoxy resin (LY 556) with room temperature curing hardener (HY 951 grade) with diluent DY 021 mix was employed as the matrix material. The carbon particles of 15 µm and the ceramic materials such as Silicon carbide and Alumina with average size of 40 µm (supplied by Snam Abrasives, Hosur) were used as reinforcement in the carbon-epoxy composite. The details of compositions are shown in Table 1

Table 1 Details of prepared composite

Samples	Epoxy (wt %)	Carbon (wt %)	SiC (wt %)	Al_2O_3 (wt %)
1	40	60	-	-
2	40	55	5	-
3	40	50	5	5
4	40	45	10	5

2.2 Fabrication Process

The fabrication process was done using vacuum bag molding. The vacuum bag molding is the modification of the wet hand layup technique. The circular mold was prepared as per required dimensions (15 mm diameter and 180 mm length). The carbon-epoxy material and ceramic particles with different volume fractions was mixed and stirred manually. The mixed materials are poured into the prepared mold. The mold was placed inside the bag made of flexible film and all edges are sealed. The bag was then evacuated, so that pressure eliminates voids in the laminate, forcing excess air and resin from the mold. The laminate was then placed in the oven with 100°C temperature and kept for 1 hour for curing completely. The cutting operation was done for cutting the laminate into dimensions required for the test such as wear test, compressive test and hardness test.

2.3 Hardness Test

Hardness is a measure of how resistant solid matter is to various kinds of permanent shape change when a force is applied. Macroscopic hardness is generally characterized by strong intermolecular bonds, but the behavior of solid materials under force is complex. Hardness is an important characteristic which affects the wear behavior of the bearing material. Hardness depends on ductility, elastic stiffness and visco elasticity. The specimen is prepared as per ASTM D 785 – 08 standards and size of the specimen is 12 mm x12 mm. An appropriate scale is chosen to be used. The indenter moves down into position on the part surface. A minor load is applied and a zero reference position is established. The major load is applied for a specified time period (dwell time) beyond zero. The major load is released leaving the minor load applied. The Brinell hardness number is a function of the test force divided by the curved surface area of the indent. The indentation is considered to be spherical with a radius equal to half the diameter of the ball. The average of the two diagonals is used in the following formula to calculate the Brinell hardness. The intender used was 2.5 mm ball intender with a load of 187.5 N.

Fig 1 Hardness Testing Machine

2.4 Compressive Test

Compressive strength is the capacity of a material or structure to withstand loads tending to reduce size. It can be measured by plotting applied force against deformation in a testing machine.The testing will be conducted using Universal testing machine. Some materials fracture at their compressive strength limit. Measurements of compressive strength are affected by the test method and conditions of measurement. The compressive strength is important characteristics of a bearing. The compressive strength is usually obtained experimentally by means of a compressive test. The apparatus used for this experiment is the same as that used in a tensile test. The specimen is prepared as per ASTM D 695 standards. The size of the specimen is 12.7 mm x 25.4 mm.

Fig 2 Universal Testing Machine

2.5 Wear Test

Wear occurs as a natural consequence when two surfaces with a relative motion interact with each other. Wear is defined as the progressive loss of material from contacting surfaces in relative motion. The wear test (dry sliding wear test) was performed on the fabricated composite is a type of adhesive wear. This type of wear is caused between two metallic components which are sliding each other under an applied load and in an environment where no abrasive are present. Dry wear test will be carried out on the pin-on-disc apparatus. The wear test specimen was prepared with diameter of 8 mm x 30 mm length and test was conducted under varying loads as per ASTM G-99 standard. The disc used was an alloy steel with 165 mm diameter and 10 mm thickness. The hardness of the disc is 62 HRC. The test was conducted for a specified test duration, applied load and sliding velocity. The surface of the specimen was perpendicular to the contact surface, prior to testing, the surface of both the specimen and the disc were cleaned with a soft paper soaked in acetone before the test. The initial and final weight of the specimen was measured by using an electronic digital balance. The difference between the initial and final weight is the measure of weight loss.

Fig 3 Pin-on-disc apparatus

The weight loss was then converted into the wear volume using the density data. The specific wear rate (Ws) parameter provides a more comprehensive measure of the wear loss characteristics of the materials.

3. Results and Discussions

In the present work, the friction and dry sliding wear behavior of carbon-epoxy composite without addition and with addition of ceramic particles were studied. The ceramic particles are added from 5% to 10%. The composite samples were studied in terms of the coefficient of friction and specific wear rate. The compressive strength and hardness are also studied for the samples.

3.1 Hardness

The hardness test was carried out in a Brinell hardness testing machine with ASTM standards to measure the hardness of the fabricated composites. The hardness values of composite for different compositions a\were shown in Fig 1. It is noted that the hardness value of the carbon-epoxy composite without ceramic particle is very less and addition of ceramic particle increases the hardness of the composites. This is because ceramic particles have good mechanical properties and which increases the hardness. The maximum hardness (51 BHN) is exhibited for carbon-epoxy composite with 10 % SiC and 5 % Al_2O_3.

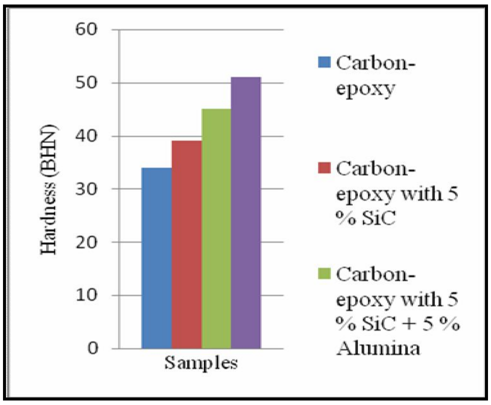

Fig 1 Hardness values for various fabricated composites

3.2 Compressive Srength

The compressive strength for the fabricated carbon-epoxy composite with addition of ceramic particle samples is shown in Fig 2. It is noted that compressive strength is low for carbon-epoxy composite without ceramic particle as 78.69 N/mm^2.

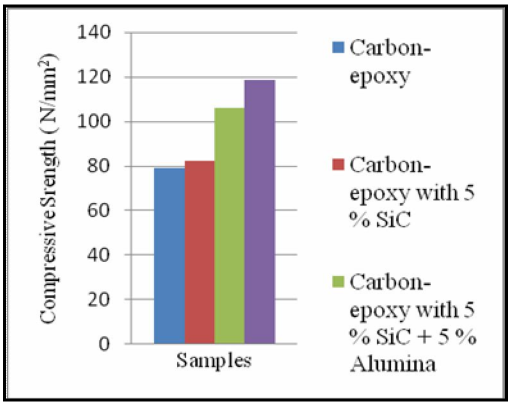

Fig 2 Compressive Strength for various fabricated composites

The strength increases with increase in weight percentage of ceramic particle content in carbon-epoxy composite. This is because ceramic particle has good mechanical properties. The highest compressive strength 118.48 N/mm^2 was exhibited for carbon-epoxy composite with 10 % SiC and 5 % Al_2O_3.

3.3 Co-Efficient of Friction

The experimental data for a constant sliding distance of 2000 m and sliding velocity of 2 m/s as a function of load were summarized. The experimental results show that the coefficient of friction increases with increase in the normal load. The coefficient of friction is shown in Fig 3. In all test conditions, coefficient friction is maximum in case of carbon-epoxy compositewithout ceramic particles and minimum in case of ceramic particles filled carbon-epoxy composites. The carbon-epoxy composite exhibits highest friction coefficient all normal loads. The friction coefficient gradually decreases with increase in ceramic particle content in carbon-epoxy composite. The friction of the composite material seems to be governed by its shear strength which influences the rupture of adhesive bonds at the interface. The carbon-epoxy composite exhibits better friction behavior since reinforcing fillers such as SiC and Al_2O_3 can effectively reduce the adhesion force. Addition of ceramic particles increases the strength and hardness of the composite. This would be reason for the reduction of friction coefficient with more percentage of ceramic particles in carbon-epoxy composite. The coefficient of friction is minimum for the composite with 10 % SiC and 5 % Al_2O_3.

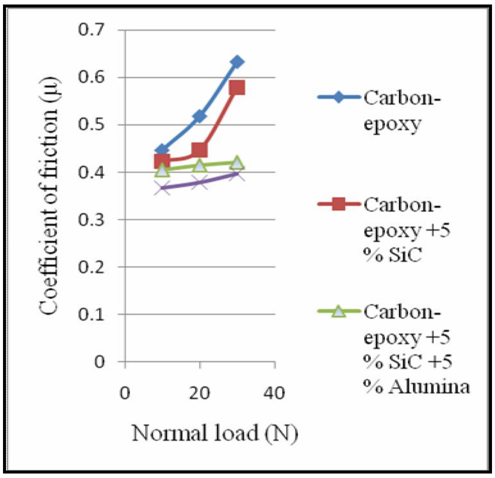

Fig 3 Comparison of coefficient of friction of fabricated composites

3.4 Effects of Loads on Specific Wear Rate

Fig 4shows the wear volume of various composites for different normal loads. The wear volume is more for higher normal loads and without ceramic particles. The variation of specific wear rate of fabricated samples such as carbon-epoxy, carbon-epoxy with 5 % SiC, carbon-epoxy with 5 % SiC + 5 % Al_2O_3, and carbon-epoxy with 10 % SiC + 5 % Al_2O_3 with different applied loads 10 N,20 N, 30 N were presented. The sliding distance, sliding velocity were kept constant at 2000 m and 2m/s respectively. SBasavarajappa et al (2012), B. Suresha et al (2010) and K.M. Subbay et al (2012) investigated the wear behaviour of epoxy composites with addition of different fillers such as SiC and graphite particles. They conclude that ceramic particles have good wear properties and high hardness which improves the wear resistance. The bonding between the ceramic and polymer composites is very good [20, 21, 22].The specific wear rate is decreased with addition of SiC particle content.For fiber reinforced polymer matrix composites, the process of material removal in dry sliding conditions is dominated by four wear mechanism viz. matrix wear, fiber wear, fiber fracture and interfacial debonding. The wear rate and wear volume increases with increase in normal load. It is seen that specific wear rate is non-linear for the samples wear rate is very high for carbon-epoxy composite without ceramic particles in Fig 5

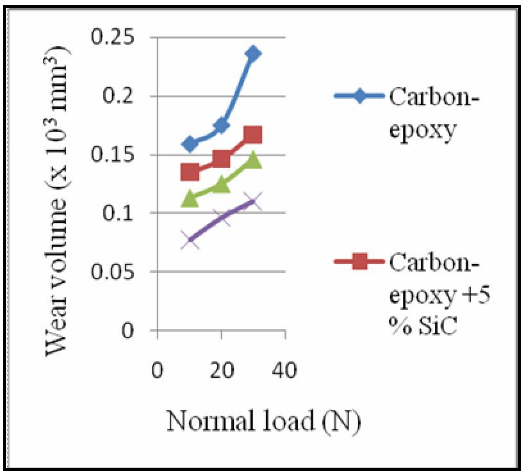

Fig 4Comparison of wear volume of fabricated composites

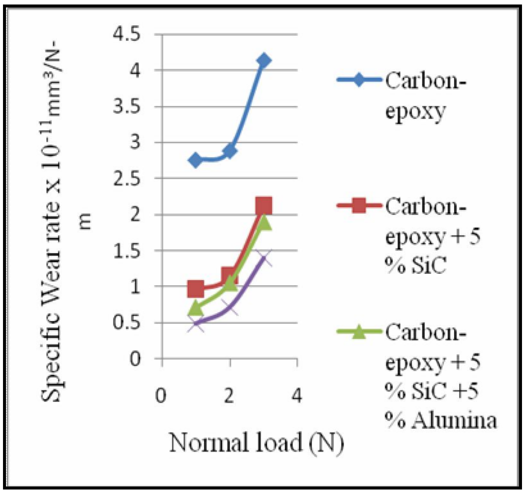

Fig 5Comparison of specific wear rate of fabricated composites

3.5 Fabrication and Testing of

Plain Journal Bearing

It is observed that addition of ceramic particles such as SiC and Alumina in carbon-epoxy composite greatly change their mechanical and tribiological behavior. From the results it is concluded that carbon-epoxy with 10 % SiC and 5 % Alumina exhibits good strength and wear resistance. The fabrication of plain journal bearing is done using vacuum bag molding and tested in centrifugal pump. Dry running test is conducted and runs for 40 Secs and it is observed that Pump was free and easy to rotate by hand after dry run test.The composite bearing for centrifugal pump is shown in Fig 6.

Fig 6 Composite Bearing

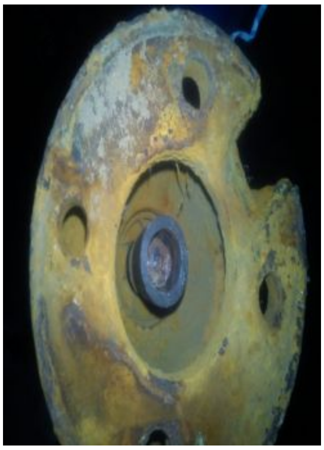

Fig 6 centrifugal pump applications   **Fig 7 plain bearing assemble sets**

Conclusions

Based on the experimental observations, it was found that the compressive strength and hardness were improved with increase in weight percentage of filler content. The specific wear rate was also decreased with increase in weight percentage of ceramic particle in Carbon–Epoxy composite. The results show that wear properties were improved with increase in weight percentage of ceramic particles. The composite with 10 % SiC and 5 % Al_2O_3 showed lower friction and specific wear rate under different loads and hence may be suitable for bearing application. The plain journal bearing was fabricated with better wear resistance, for centrifugal pump and tested.

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