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Research Article

Comparative Study on Tribological Behavior of Biaxial Glass Fiber/Al_2O_3/SiC Epoxy Journal Bearing Under Various Test Conditions

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Abstract: Composite journal bearings are becoming more popular now a day because they eliminate the possibility of seizure failure to the bearings. The major drawback of the gun metal bearings is the seizure failure. To overcome this problem, the composite journal bearings are widely used by the industries. In this study, the fiber reinforced plastic composed of glass fiber with epoxy resin composite /Al_2O_3/SiC journal bearing having the composition of 10-20% are tested under various operating conditions and the results are compared with gun metal journal bearing. This study focuses on the dimensional stability, temperature, friction, surface roughness and surface topography behavior of biaxial glass fiber epoxy composite with and without lubrication at different speeds and loads. It has been observed that the friction and temperature increases with increase in load but it's very less when compared to gun metal bearing. It is found that there is loss in weight due to increase in temperature and friction but the loss in weight is very less which is approximately 1 g. In the earlier research, most of the bearings are tested under very low speed with more catastrophic failure due to various loading conditions. Therefore in this study the composite journal bearing is tested from low speed to high speed with different loading conditions and their effects has been studied. This composite journal will save the significant cost to the industries by reducing the coefficient of friction, temperature, lubrication etc.

Keywords: Friction, glass fiber, journal bearing, surface roughness, temperature, topography

INTRODUCTION

Journal bearing is one of the important elements in the rotary machineries. It is commonly used in industrial machinery to sustain the bearing loads in any radial direction. The commonly used materials for journal bearing are gun metal, white metal, babbit, cast iron and aluminum. Because of these materials some problems has been created like comfort-ability, anti-scoring, fatigue strength and temperature investigated by Kulkarni and Chapkhhane (2012). Due to the metal to metal contact between the shaft and bearing, a large friction is developed. So due to this friction the heat is generated in large quantity provided by Kim *et al*. (2009). To avoid this situation the continuous lubrication is required. Now many of the research encouraged to use alternative material instead of the conventional metal. Among these composites, the fiber reinforced composites are the most attractive once. Today in industry the use of polymer and its composite has been increased in sliding or rolling component such as clutch, bearings, transmission belts, piston rings and rollers suggested by Suresha *et al*. (2006). All the steel materials require oil or grease lubrication for reducing temperature and friction but these polymers and composite have self lubricating properties so it does not require oil or grease is proposed by Demirci *et al*. (2011). Bhuptani and Prajapati (2013) proposed the major problem of sliding pair contact is friction and wear. The wear resistance can be increased and friction coefficient can be reduced by selecting a good material combination. Friction and wear rate depends on vibration, applied force, lubrication, relative humidity. The applied load and sliding velocity plays a major role on friction behavior of composite material. Higher the surface roughness on the journal bearing, leads to high spot contact during running conditions causing local high contact stress zones above the failure limitsprovided by Labasova (2013). Gururajan and Prakash (1999) investigated the operating surfaces of journal bearing have more impact on the gap height size. Hence, it is required to predict the surface roughness of journal bearings. These composite materials have high tensile strength, less expensive, low density and low coefficient of friction. Another important fact of increase in the use of composites is its high strength to weight ratio which gives it an extra edge over the existing bearing material proposed by

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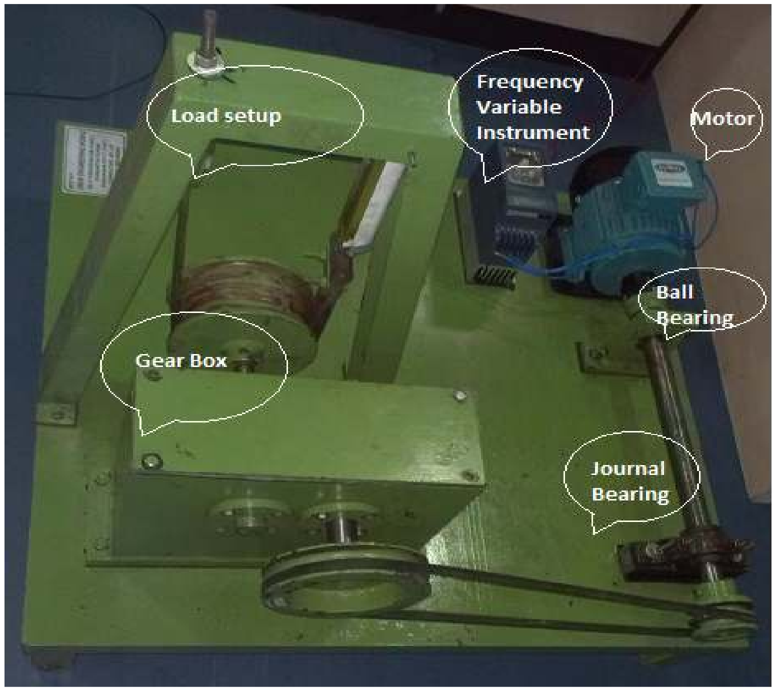

Fig. 1: Experimental setup

Feyzullah and Saffak (2008). The wide varieties of composite materials are available which can be used as a substitute for the existing bearing materials without compromising its strength and durability provided by Ünlü *et al*. (2009). Bazhenov and Kozey (1991) described the unidirectional glass fibers possess more failure than that of biaxial fiber. In this study, the composite material biaxial glass fiber /Al_2O_3/SiC with epoxy resin is used for the journal bearing and it is tested for various speed and loading conditions and for these conditions various temperatures are measured. The various surface roughness parameters are also measured by conducting the dry run test.

In this study, the tribological behavior of journal bearings made from biaxial glass fiber/Al_2O_3/SiC with epoxy resin composites and gun metal under various operating conditions. Then the results of the experiments were analyzed and are compared with the graphs. In this study a new journal bearing tester shown in Fig. 1 was constructed to determine the tribological properties of both glass fiber composites and gun metal journal bearings. A series of speed tests were carried out under various normal loads in the journal bearing tester were investigated. The tribological behaviors were evaluated by measuring the friction surface temperature and friction coefficient as a function of the applied normal load. Also, the wear rate is measured with respect to volume fraction and applied loads. The microstructures of the composite journal bearing were analysed through surface roughness tester, Scanning Electron Microscopy (SEM) and Atomic Force Microscope (AFM).

MATERIALS AND METHODS

Fabrication: The composite material is made up of biaxial glass fiber with epoxy resin as shown in the Fig. 2. The following procedure is adopted to make this composite.

First the wax is applied on the tool's upper and lower surface as a releasing agent to remove the tool from that mould. Then E-glass sheet of 300 GSM is cut as per the tool in eight numbers. Then the mixture of Resin LY556, Hardener HY 951, 10 to 20% of silicon carbide and aluminium oxide is added to the total weight of the specimen is made. For fabrication of this bearing, the resin of 30 g is required. In this mixture, chop strand of E-glass is used to fill the cavity to avoid the air bubbles. After that 8 layers of the sheet and mixture laid into the female tool and clamped it with the male tool. Finally the part of 2.4 mm thickness is made in which each layer is of 0.3 mm thickness. Then clamped assembly is kept for room temperature curing for 12 h. This model with the tool is kept in hot air oven for post curing up to 100°C. At last that model is removed from the tool and trimmed the extra edges so as to gain the original dimensions.

Experimental set up and testing: The various kinds of test were performed to observe the tribological performance of the composite journal bearing. They are revolution test, loading test, dry sliding test, vibration test and surface roughness test. The revolution test is investigated with different temperature of the bearing

Fig. 2: Raw material and tools used for fabrication

Fig. 3: Before and after dry test

surface. The load test is to investigate the damage of journal surface and bearing surface by repeating friction force. The dry lubrication test is investigated to ensure the durability and strength of composite journal bearings. The vibration test is investigated to measure amplitude of vibration. Finally surface roughness test is conducted to predict various roughness parameters.

Experimental set up and procedure: The experimental set up as shown in the Fig. 1 consists of motor of 0.37 KW, shaft, bearing, pulley, transmission belt and gear box. The speed is varied with the help of frequency variable instrument. The load is applied through belt drive which is connected to load setup with gear box.

Speed and load test: First the revolution test was conducted with different speeds of about 600, 800, 1000 and 1200 rpm at about 10 min each, respectively. At every 2 min the temperature of bearing interface was measured with the help of temperature measuring device. Also the vibration signals were recorded for every 3 min with accelerometer sensor. In the load testing, three types of load 0.244, 0.336, 0.830 kg, respectively were applied at different speeds. By varying load and speed the temperature for every 10 min are measured. From this test, damage of journal and bearing surface are investigated by varying different loads. Then the coefficient of friction for the composite journal bearing is calculated.

Dry run test: The final test is dry run test as shown in Fig. 3. The shaft is made up of steel and the bearing is of biaxial glass fiber with epoxy resin. In this the shaft is rotated for 1 h at 800 rpm continuously. Then for every 5 min the temperature at middle interface of bearing is recorded. In this, the wear of bearing surface and shaft surface is observed due to no lubrication. No critical damage on the bearing surface, but small wear debris is observed on the shaft surface.

RESULTS AND DISCUSSION

The speed test, load test, dry run test, temperature test, vibration test and surface roughness test has been carried out through experimental set up. After conducting various test, the dimensional stability of glass fiber epoxy journal bearing and gun metal journal bearing are measured with the help of vernier caliper. The dry run test is conducted and the temperature is plotted with respect to time. The coefficient of friction is measured for both the composite journal bearing and the gun metal bearing, the graphs are plotted with respect to various loads. The sliding velocities of the journal are calculated and the graph has been plotted with respect to temperature. Finally, the surface roughness test is conducted for composite bearing and gun metal journal bearing to calibrate the roughness parameters, before and after the dry run test. Table 1 to 3 shows the dimensional stability of composite material over gun metal. The difference of readings before and after the test for composite material is negligible. For composite there is contraction in readings of length and diameter, it is because of different material used for journal and bearing. Composite material has greater the coefficient of thermal expansion than the steel journal. The most important parameter for the use of composite is it's less weight and very small reduction in the weight after the test.

From the graphs Fig. 4 and 5, as the time increases, the temperature also increases, but it clearly indicates that the temperature of gun metal is more than that of composite during the dry run test with load and without loading conditions. Also, due to continuous contact between mild steel journal and gun metal bearing an increased temperature is observed (Fig. 6).

Coefficient of friction: Figure 7 and 8 are showing that the coefficient of friction increased gradually, as the load was increased, but with the comparison of gun metal the glass fiber epoxy shows very less coefficient of friction, because of self lubricating characteristics of composites and it is observed that the journal rotates inside the bearing very smoothly due to less local asperities present in the composite bearing. However, it was found that the composite bearing operates with low vibration and noise level.

From the Fig. 8 it is clearly indicated that the gun metal having more coefficient of friction, due to continuous metal to metal contact between the shaft and the bearing and the increased temperature of oil lubrication. Due to the presence of large asperities, it was found that increased level of noise and vibration. This will lead to the failure of the bearings.

Table 1: Properties of E-glass

Properties	Value
Density (g/cm³)	2.5
Tensile strength (MPa)	2000-3000
Young's modulus (GPa)	70
Elongation at break (%)	2.5
Specific tensile strength (MPa/g.cm³)	800-1400
Specific young's modulus (GPa/g.cm³)	28

Table 2: Dimensions of gun metal bearing

	Gun metal		
Parameters	Before test	After test	Difference
Bore diameter (mm)	25.410	25.670	0.260
Length (mm)	50.510	50.800	0.290
Weight (kg)	0.248	0.245	0.003

Table 3: Dimensions of composite bearing

	Glass fiber/Al_2O_3/SiC/epoxy		
Parameters	Before test	After test	Difference
Bore diameter (mm)	25.310	25.250	0.060
Length (mm)	50.770	50.750	0.020
Weight (kg)	0.048	0.047	0.001

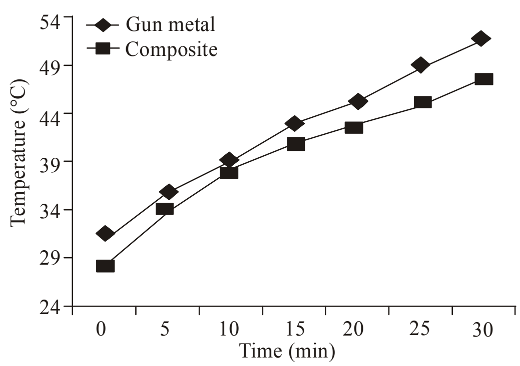

Fig. 4: Graph for dry test without load

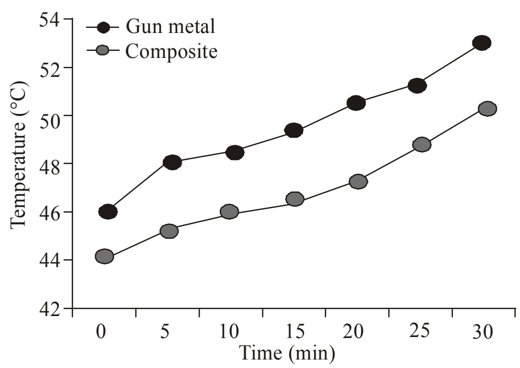

Fig. 5: Graph for dry test with 0.336 kg load

Fig. 6: Composite journal bearing

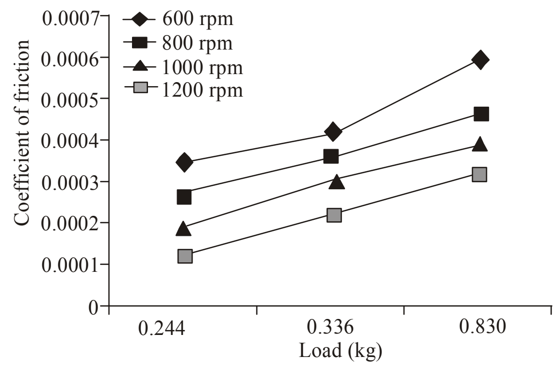

Fig. 7: Load v/s coefficient of friction graph for composite

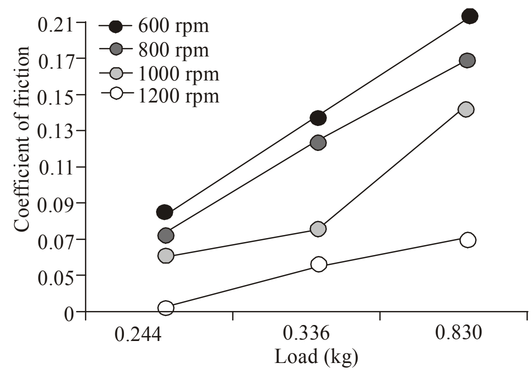

Fig. 8: Load v/s coefficient of friction graph for gum metal

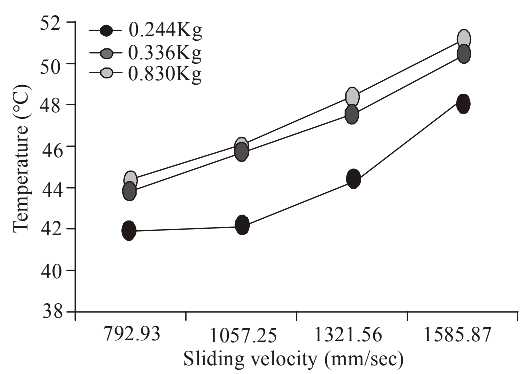

Fig. 9: Sliding velocity v/s temperature graph for composite

Sliding velocity: Figure 9 and 10 shows the interface temperature of journal bearing increases with the sliding velocity for different loading conditions. For composites the maximum temperature is 51°C but the temperature for the gun metal is reached to 60°C. From the results, it is found that the operating temperature of composites is less than that of the gun metal bearing and however it is within safe limits.

From the Fig. 10, it was observed that as the sliding velocity was increased, the viscosity of oil is decreased. So, the temperature of the bearing is increased with large asperities. When comparing the two graphs Fig. 9 and 10 the composite journal bearing

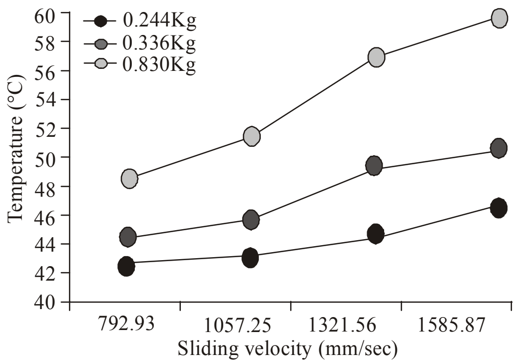

Fig. 10: Sliding velocity v/s temperature graph for gun metal

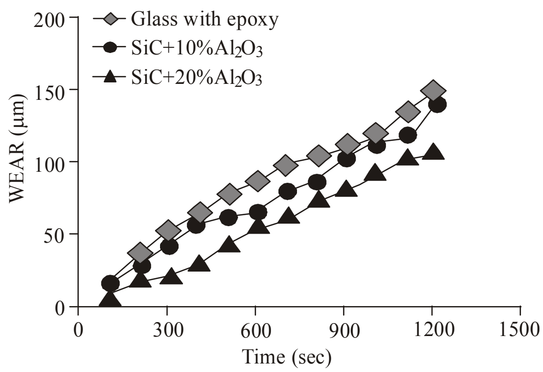

Fig. 11: Time vs. wear graph for 50 N

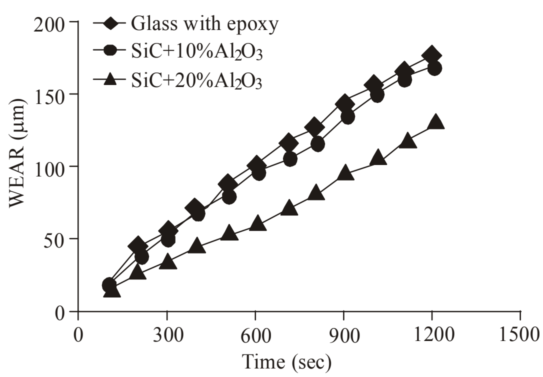

Fig. 12: Time vs. wear graph for 100 N

is more efficient than gun metal bearings during high speed operating conditions due to its excellent self lubricating properties.

Wear characteristics of the composite materials: Wear influence mechanical properties of materials, micro-geometry of surface and geometry of contact. As an additional factor affecting on the wear may take the shaft absolute peripheral speed value. Adhesion wear is associated with adhesive connection between friction surfaces. Physical and mechanical properties of material have a general influence on the adhesion force value. The volume of wear material is calculated by Eq. (1):

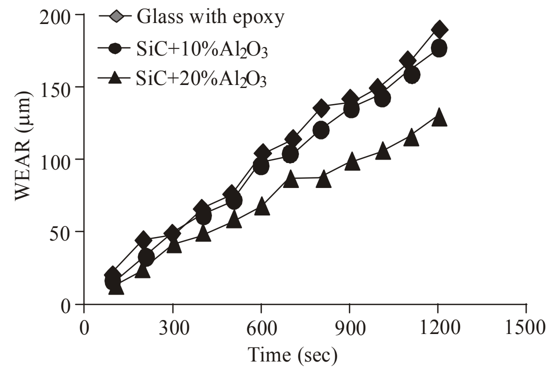

Fig. 13: Time vs. wear graph for 150 N

$$V_a = \frac{K.N}{H}.V.t \quad (1)$$

where,
Va = Volume of wear material, m^3
K = Constant of wear, m^3/MPa.m
N = Bearing average pressure, MPa
H = Hardness of softer material
V = Shaft peripheral speed, m/sec
t = Bearing couple uptime, sec

Also, the coefficient of wear is:

$$K_{wear} = \frac{V_{wear}}{V.t.N} \quad (2)$$

where,
V_{wear} = Wear material volume, mm^3
t = Processed time, sec
V = Shaft peripheral speed, m/sec
N = Average bearing pressure, MPa

The test was carried out by applying normal load (50 to 150 N) and run for a constant sliding distance. At the end of the test, the specimen assembly was again weighed in the same balance. The difference between the initial and final weights was a measure of slide wear loss. A minimum of three trials was conducted to ensure repeatability of test data. The friction force at the sliding interface of the specimen was measured at an interval of 5 min using a frictional load cell. The coefficient of friction was obtained by dividing the frictional force by the applied normal force. Selected samples were coated with a thin layer of gold on the worn surface and subjected to microscopic examination using scanning electron microscope.

When the two sliding surfaces come into contact, asperities of the softer surface were easily deformed and some were fractured by the repeated loading action. These repeated loading action caused crack nucleation under the very near surface and further loading and deformation caused cracks to extend and propagate, joining neighboring ones. The cracks propagated along the week part, i.e., interface between fiber and matrix, the fiber fracture occurred by repeated loading.

It is seen from Fig. 11 to 13 that the filler in G-E composites appears to influence the friction and wear behavior. The wear losses of the composites decreases with filler addition and show the maximum wear resistance (least wear loss) for Al_2O_3/SiC-filled G-E and the least for unfilled G-E).

Also, from the above graphs, it is observed that the Inclusion of Graphite, Al_2O_3 and SiC particulate fillers contributed significantly in reducing friction and exhibited better wear resistant properties.

Al_2O_3 and SiC particulate carbide filled G-E composite shows higher resistance to slide wear compared to plain G-E composites.

Wear rate increases as working load increases, but this increase is not gradual as load increases.

Wear increases as the velocity increases. But this increase in the wear rate slows down as the velocity increases.

For dry testing conditions, wear value ranges up to 240 µm for different loading conditions.

For lubricated conditions, wear value ranges up to 30 µm for different loading conditions.

Increased wear resistance and reduced coefficient of friction are positive traits, which make the composite suitable to be used as liners in coal handling equipments.

Analysis of wear results using a 3-D response graph: The Response Surface Methodology (RSM) is a collection of mathematical and statistical techniques useful for designing a set of experiments, analyzing the influencing parameters and expressing the values graphically.

To obtain the influencing nature and condition of the process on wear, the surface plots are developed considering two parameters in the middle level and two parameters in the X- and Y-axis, as shown in Fig. 14 to 17. These response surface graphs can help to predict the wear (response) for any zone of the experimental field.

The peak of the response plot shows the maximum wear. As the applied load increases and the percentage of composition of composite increases the wear also goes to increase shows in red color. But when the percentage of composition is 20% the wear is at minimum level in the case of composites. From the results it is observed that wear rate of the composite is closer to the gun metal journal bearing.

Scanning electron microscopy: The slide wear data in respect of select samples are discussed based on the Scanning Electron Microscopic (SEM) features. The SEM pictures of composite Sample shown in Fig.18 to 20 pertaining to the test conditions of 50, 100 and 150 N, at 2 m/sec, respectively are considered for interpretation.

The SEM picture of composite sample subjected to a load of 50 N and sliding velocity 2 m/sec is shown in

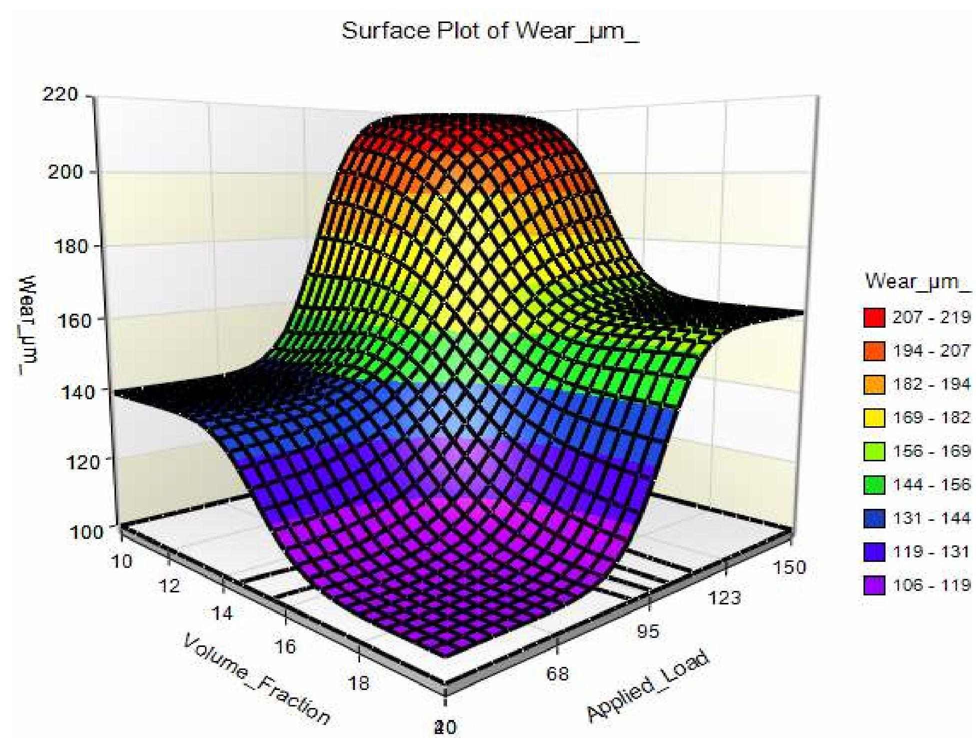

Fig. 14: 3D-applied load vs. volume fraction vs. wear for composite

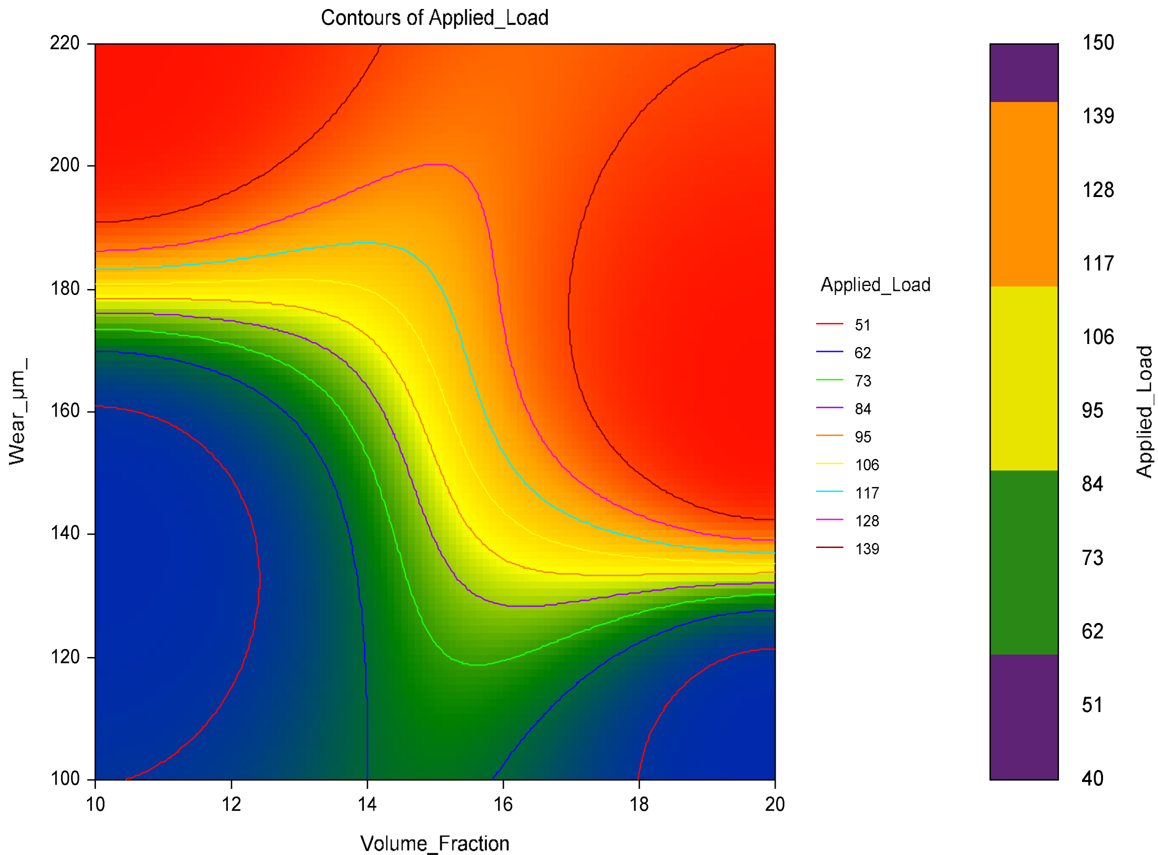

Fig. 15: 2D-applied load vs. volume fraction vs. wear for composite

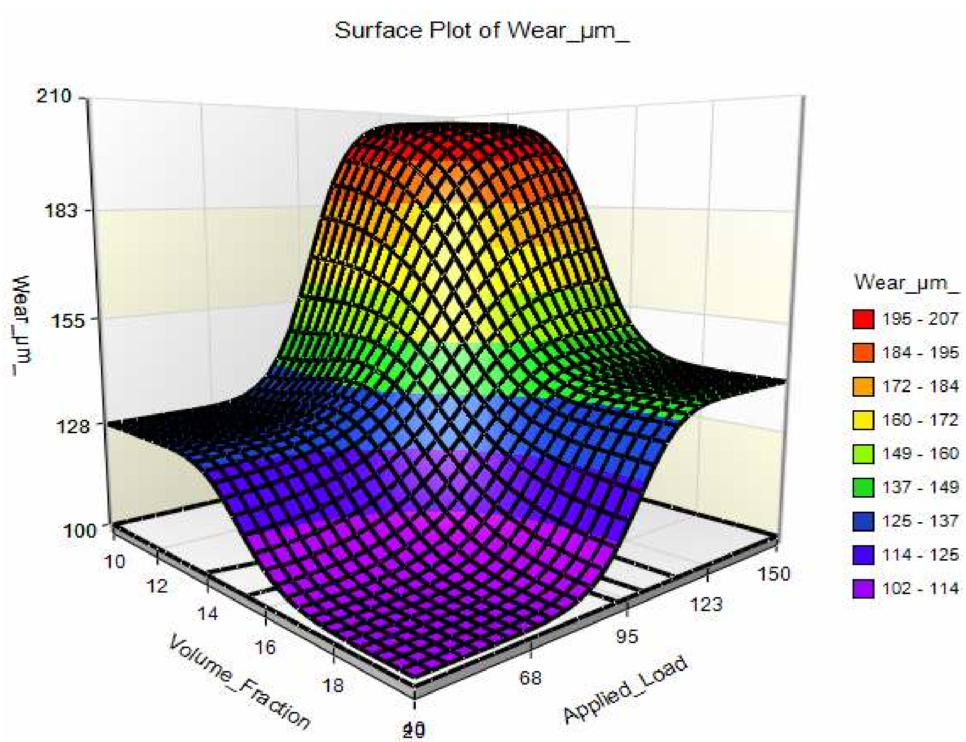

Fig. 16: 3D-applied load vs. volume fraction vs. wear for gun metal

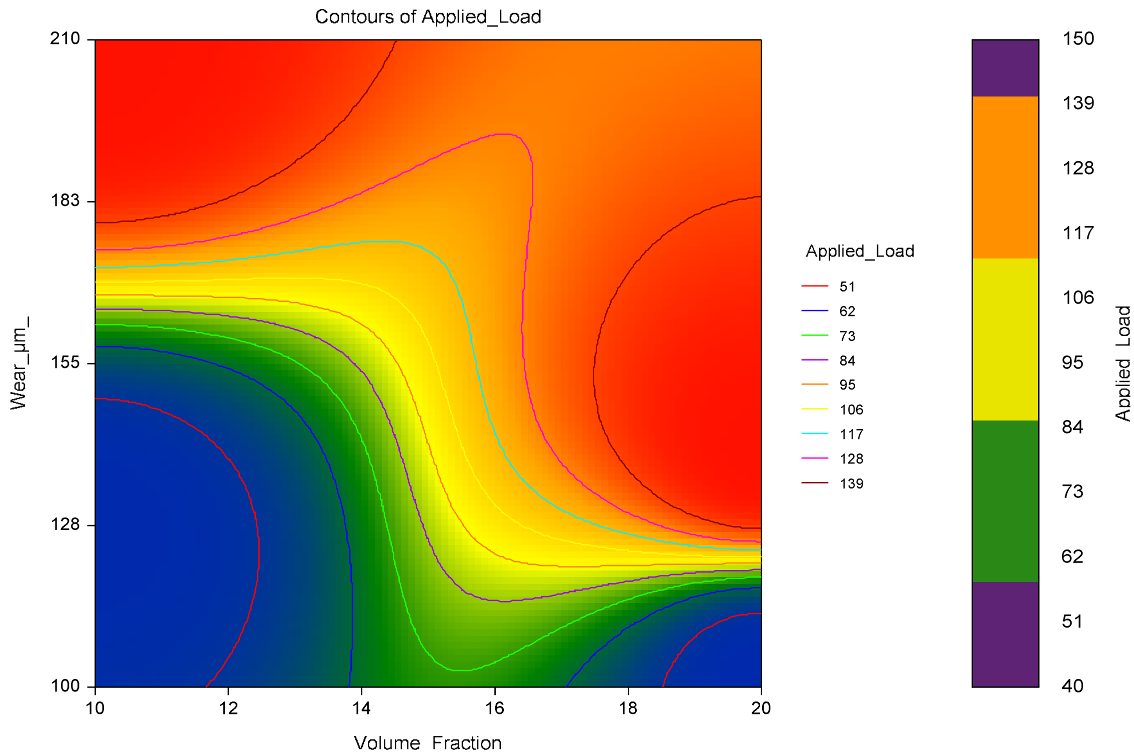

Fig. 17: 2D-applied load vs. volume fraction vs. wear for gun metal

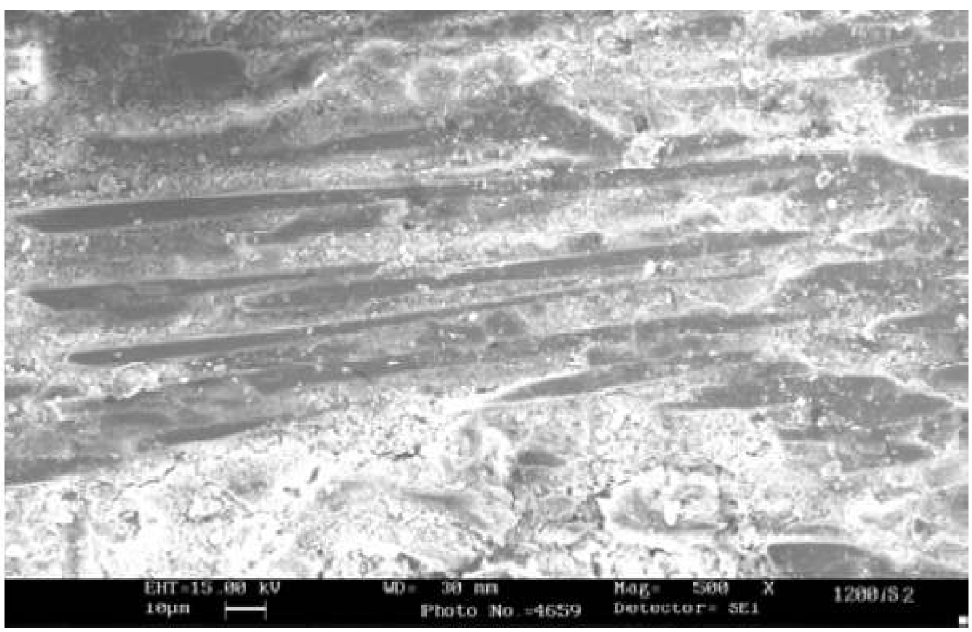

Fig. 18: SEM picture of composite at 50 N at 2 m/sec

Fig. 18. The spread of the matrix and fewer wear debris formation are noticed. In Fig. 19, it is noticed that the debris begins to cluster around the fibers. When Fig. 20 is compared with the Fig. 19, it is obvious that with application of higher load, there has been observed increase of more breakage of fibers and further the broken fibers show inclined type of fracture. These observations are in accordance with experimental wear test data presented in Fig. 14.

Roughness parameters for glass fiber with epoxy: The surface roughness of the material plays a major role in tribological characteristics of journal bearing. The operating surface of the sleeve is made up of glass

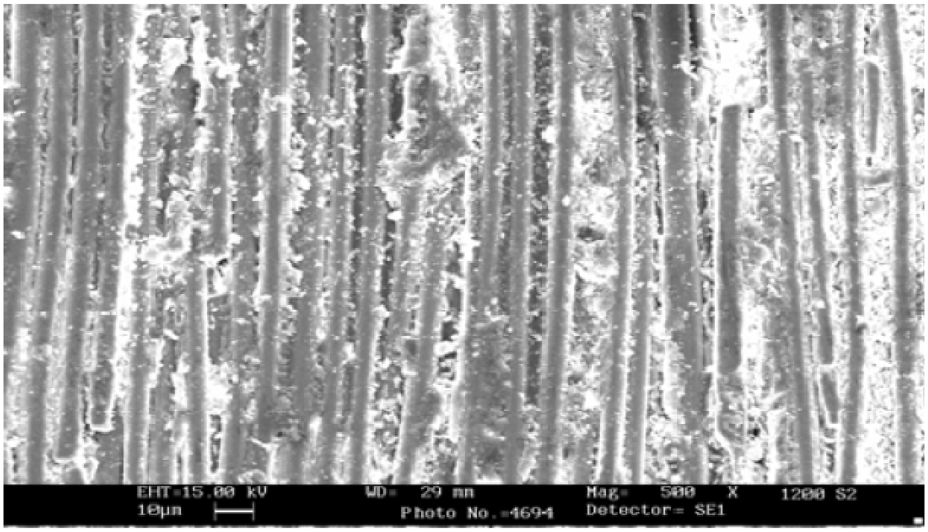

Fig. 19: SEM picture of composite at 100 N at 2 m/sec

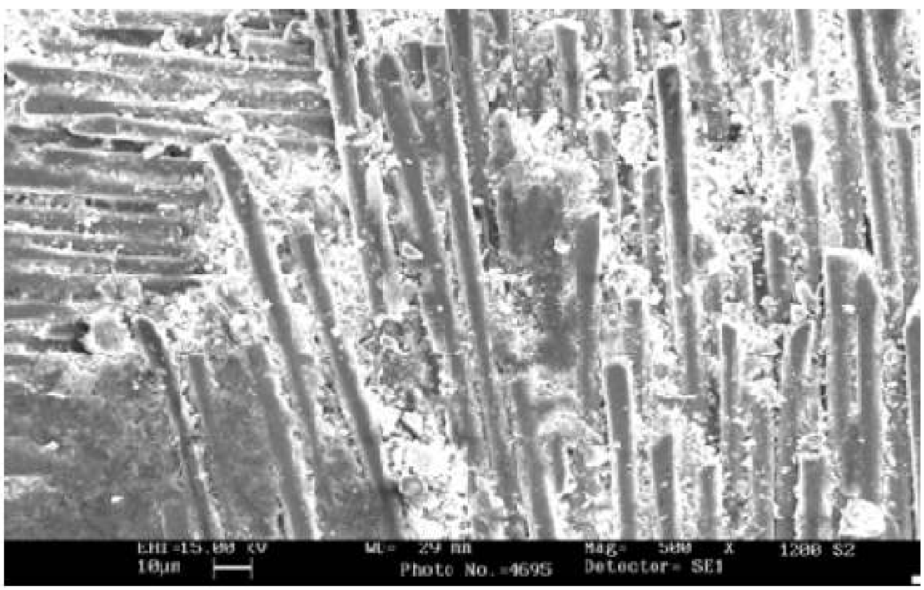

Fig. 20: SEM picture of composite at 150 N at 2 m/sec

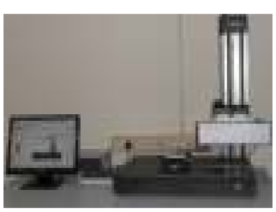

Fig. 21: Surface roughness tester

fiber/Al_2O_3/SiC with epoxy resin. The bearing sleeve is tested with before and after the dry run test in MarSurf GD120 surface roughness tester as shown in Fig. 21. The ISO, JIS, ASME (N+2xLC) standards is followed with the length of 5.60 mm, measuring speed of 0.5 mm/sec and measuring interval of 0.5 μm.

Form Fig. 22 it was found that the average roughness R_a for the glass fiber epoxy, before dry test is 0.4661 μm and maximum roughness height R_t is of 4.1802 μm. From the Fig. 23 it is found that after the dry run test the average roughness R_a is 0.5270 μm and maximum roughness height R_t is 4.8487 μm. This shows that after dry run test a considerable value of average roughness and maximum roughness height is increased.

It was found that after the dry run test the values of roughness parameters were increased because of asperities formation in the composite journal bearing. However the asperities formation in the composite bearing is less than that of gun metal bearing. In the gun metal bearing, due to the absence of oil, much strain on

Fig. 22: Roughness plot before dry run test for composite bearing (Ra = 0.4661 µm)

Fig. 23: Roughness plot after dry run test for composite bearing (Ra = 0.5270 µm)

Fig. 24: Roughness plot before dry run test for gun metal bearing (Ra = 0.8787 µm)

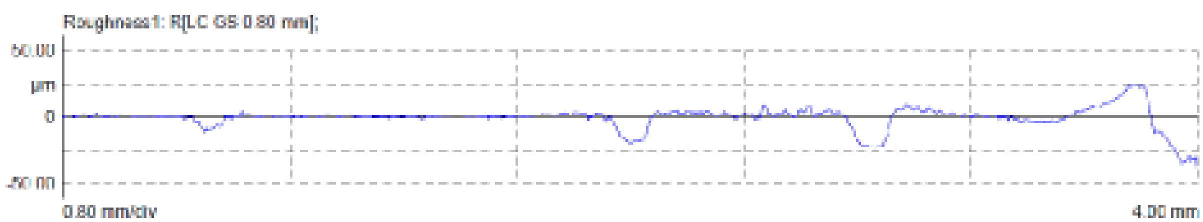

Fig. 25: Roughness plot after dry run test for gun metal bearing (Ra = 4.6848 µm)

the bearing is takes place. Also, the continuous metal to metal contact between the journal and bearing leads to increased temperature. So, that the corrosion and followed by erosion was takes place.

In this study, a filter technique is employed to separate and extract the roughness and waviness elements of the surface of the journal bearing. The filtered surface records the nature of real waveform, shape and amplitude within a permitted cut-off wavelength.

Roughness parameters for gun metal: From Fig. 24 for the gun metal it is found that the average roughness R_a, before the dry run test is 0.8787 µm and the maximum roughness height R_t is of 6.9038 µm. From Fig. 25, after the shaft rotation of 60 min, i.e., after dry run test, the average roughness R_a is found to be 4.6848 µm and maxium roughness height R_t is of 62.3556 µm.

For the gun metal the results shows that after dry run test a value of average roughness and maximum roughness height is increased due to continious metal to metal contact between the journal and bearing. From the results, it shows that when compared to gun metal the hybrid composite journal bearing having less surface roughness value and also it clearly indicating that the composite posses a very good tribilogiacal characteristics.

Surface topography using AFM: The measurements results of surface topography of different types of slide bearings sleeves have been presented. The research has been conducted with the use of Atomic Force

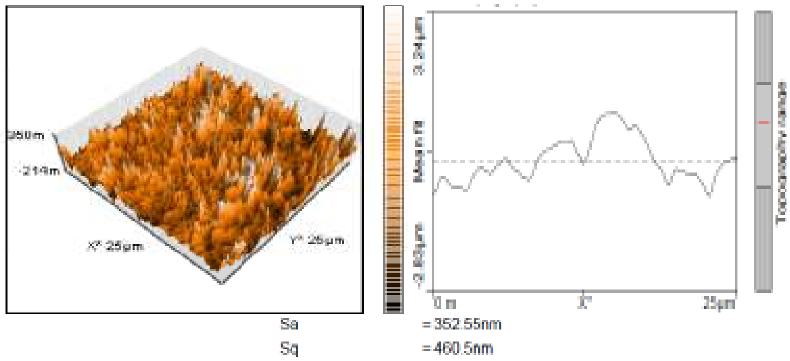

Fig. 26: Surface topography of bearing sleeve made of biaxial glass fiber/Al_2O_3/SiC. 3D view and cross-section, for non-used bearing sleeve

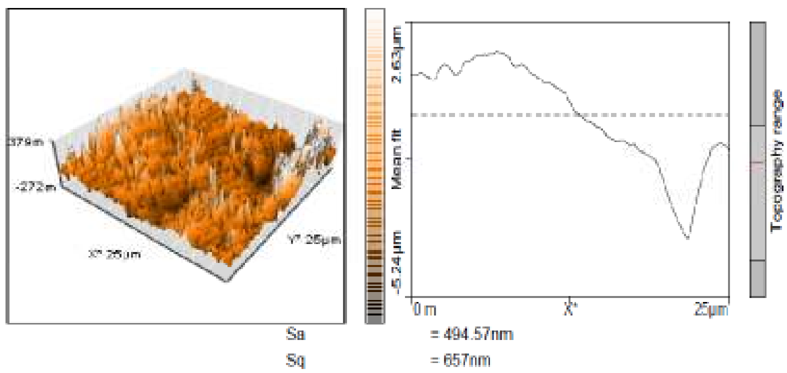

Fig. 27: Surface topography of bearing sleeve made of biaxial glass fiber/Al_2O_3/SiC. 3D view and cross-section, for used bearing sleeve

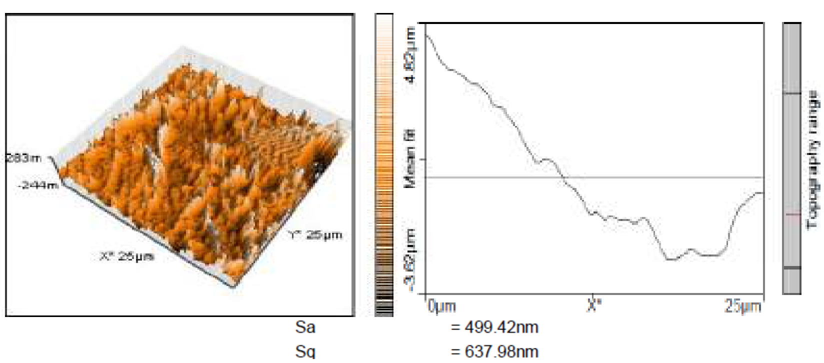

Fig. 28: Surface topography of bearing sleeve made of gun metal. 3D view and cross-section, for non-used bearing sleeve

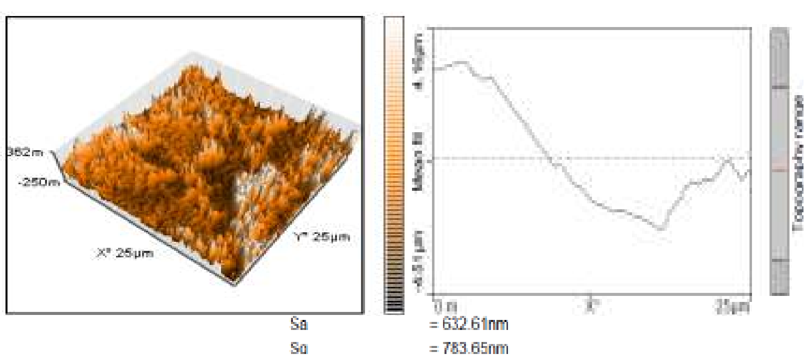

Fig. 29: Surface topography of bearing sleeve made of gun metal. 3D view and cross-section, for used bearing sleeve

Microscope (AFM). The results of measurements of surface topography were presented in the form of surface topography maps, three-dimensional graphs and some examples of selected cross-sections of investigated surface in the form of profile graphs.

Measurements of surface topography were made for thin-walled sleeves of slide journal bearings covered with glass fiber with epoxy resin composite /Al_2O_3/SiC and gun metal. Operated and new sleeves have been considered with the use of Atomic Force Microscope Nanosurf Inc., Switzerland. Presented in the study results of surface topography measurements also include the calculated values of average deviation profile Sa and Sq and the value of fixed distance between the lowest and highest inequality. In these investigations new and used journal sleeves were taken into consideration. Investigated samples are presented in Fig. 26 to 29. From results, it can be observed, that non-used bearing sleeves roughness has slightly lower value than roughness of used bearing sleeves. The greatest values of roughness is for used bearing sleeve made of composite-the Sa parameter (arithmetic average of roughness) is about 494.57 nm, while for unused bearing sleeve Sa is about 352.55 nm. For the gun metal it is observed that due to metal to metal contact between the shaft and bearing, more strain on the bearing sleeve takes place. Hence, when compared to composites, gun metal have more surface roughness (Sa) of 632.61 nm. Visible scratches on surfaces are significantly increasing value of Sa parameter. The scratches are the effect of wear of bearing sleeve surface related to operating in inappropriate conditions, such as mixed friction, boundary friction or can be caused by foreign substances, which occur in lubricant-oil used in studied bearings as a lubricant worked without filtration.

CONCLUSION

In this study, the biaxial glass fiber/Al_2O_3/SiC epoxy journal bearing was manufactured and tested under various conditions and compared with gun metal bearing. The experiment is conducted to analyze the behavior of composite journal bearing. After the complete analysis of the results it was concluded that, the bearings made of composite has good performance as compared to gun metal. In the case of composite bearing, as the coefficient of friction was very less, heat generated was also less. However, under the dry lubricating condition the composite bearing showed the good tribological characteristics due to the good thermal property of epoxy resin and self-lubricating characteristics of glass fiber. At the time of dry testing as the time increased, the temperature variation in composite bearing was less but in gun metal bearing it was more. The surface roughness of composite is also less when compared to gun metal journal bearing, leads to decreased coefficient of friction. From the test results, it is found that the composite journal bearing may solve the problems that were faced with gun metal bearing. Also the wear rate is decreased when the composition of the composite is increased.

The glass fibers significantly reduce the coefficient of friction and this enables the contact to carry higher loads and slips before the melting point of the matrix is reached. From the in wear tests of the composites against a metallic counter face where the introduction of fiber reinforcement significantly reduced the wear. When the composites run against an identical surface a buildup of fibers may increase wear because of fiber interaction. The wear process appears to differ from that of SiC and Al_2O_3 and involves the formation and removal of a thin surface layer of resin and fiber fragments. The tested glass-fiber reinforced material appears to offer the greatest benefit, reducing the coefficient of friction by a factor of around four from that of the unreinforced gunmetal used in general. This reduction will also reduce component temperatures allowing higher duties to be sustained. Thus the composite journal bearing will produce significant cost saving by reducing the maintenance cost like oil cost, labor cost, etc.

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