COMPARISON OF SURFACE ROUGHNESS EFFECTS ON FIBER MATRIX AND METAL MATRIX COMPOSITE JOURNAL BEARING

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Abstract

In the current trends, composite plays a major to reduce the coefficient of friction in the journal bearings. This paper presents the surface roughness analysis on both composite and gun metal bearing. During relative motion of two bodies, in their contact areas forces responsible for friction, wear and change of surface roughness are generated. Present contribution deals with measurement of surface roughness at the contact areas of the rotational sliding pair. Evaluated and analysed are the parameters of surface roughness of steel and biaxial glass fiber bushings, creating the frictional pair under consideration in this paper. Measurements were made before and after testing the pair. Tests were realized by the experimental set up by changing loading force, sliding speed and duration. Roughness parameters Ra, Rz were detected using the surface roughness tester MarSurf GD120. Finally, the results shows that the the composite journal bearing (GEA2S2) has less surface roughness value and posses excellent tribological characteristics.

Keywords: Composite Journal bearing, Gun metal bearing, surface roughness, maximum height of profile, arithmetical mean.

1. Introduction

Tribological processes are in progress within layers forming the contact surface. Real surface is that surface which bounds the body and separates it from the surrounding environment. Technically it is not possible and often not even technologically necessary to produce ideally smooth and frictionless surfaces at the present time. Real surface of industrial parts is characterized by a degree of surface roughness. Surface roughness is defined as the sum of the surface irregularities in relatively small distances incipient as a consequence of actual technology used in production[1]. Surface roughness is the geometrical characteristics of the surface; however, methods and equipments allowing its direct measurement are absent. Measured are certain suitable characteristics and parameters, which serve as the criterion of surfaces roughness [2]. In practice the roughness is most frequently measured by tactile profile...
method. Stylus instrument scans the surfaces of measured object, evaluates observed deviations and calculates the relevant parameters.

When performing the design calculations on the flow and operating parameters of bearings with a small diameter, one should take into account the impact of roughness height on the lubrication gap height changes of such bearing. In the Reynolds equation, the height of the oil film occurs in the third power, therefore the change in this height strongly influences on the flow and operating parameters of the slide journal bearing. Such an effect may be taken into account, inter alia, by using the stochastic method [3, 4, 5]. This method involves determining the probabilistic expected value operator on the pressure and bearing gap height function occurring in the Reynolds equation [6].

To perform these random procedures, it is necessary to find the probability density function for abovementioned quantities. This function can be determined from the measured distribution of surface topography ordinates and the distribution of roughness tops on the sliding cooperating surface [6]. The measurements of the ordinates of surface topography with a significant height of roughness tops can be performed on the contact or contactless profilometers.

The aim of this work is to measure the ordinates of surface roughness of the composite slide journal bearings sleeves and journal, including an analysis of the obtained results. Measurements of surface roughness tops in µm can be executed with a surface roughness tester.

Fundamental source of information is therefore the surface profile, which is generated by cutting the actual surface by well-defined surface. Computing system for the evaluation of the parameters of the surface profile, which is used in referenced standard, is based on the system of the mean line for the roughness profile, on the waviness of profile and on the primary profile mean line [7 - 9]. The roughness profile mean line is a line of profile with long wavelengths suppressed by profile filter. The arithmetical mean deviation $Ra$ of the profile under assessment and the maximum profile height $Rz$ are considered to be the most common parameters for assessment of the surface roughness. The parameter $Rz$ gives less information about general condition of surface, but it takes into account random extreme irregularities of the surface and therefore is a suitable complement of parameter $Ra$. Parameters $Ra$ and $Rz$ belong to the class of amplitude parameters.

2. Experimental Set-up

The test rig was developed has three subsystems namely mechanical system, an electrical control system and a measurement system. The mechanical system has the ability to simulate typical bearing operating conditions and the electrical control system allows the mechanical subsystem to be controlled for different tests.
A mechanical system was designed to operate the journal bearing. The experimental system consists of a three phase AC driving motor, couplings, load set up, a ball bearing, a journal bearing with the main drive as the shaft. The load set up is placed at one end of the test rig. The electric drive motor is connected to the main shaft which is coupled with a hard rubber.

The journal bearing is tested and it is mounted at the right end of the drive train. In order to maintain the axial displacement of the journal bearing, a pair of washers is installed on the fasteners. The washer acts as a stopper to prevent axial movement and it also serves as a thrust bearing. The preliminary experimental results showed that the high radial loading of the journal bearings generate a high temperature. In order to reduce the temperature, a rolling bearing is placed between the motor and the journal bearing. Table 1 shows the dimensions of the journal bearing made of composites.

**Table 1 Dimensions of the Journal bearing made of composites.**

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bore diameter (mm)</td>
<td>25.5</td>
</tr>
<tr>
<td>Length (mm)</td>
<td>50.51</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>0.248</td>
</tr>
<tr>
<td>Maximum load(N)</td>
<td>175 N</td>
</tr>
<tr>
<td>Maximum speed (rpm)</td>
<td>3700</td>
</tr>
</tbody>
</table>

3. Materials and Methods

This section discusses selection of materials, material composition, characteristics of composite material and fabrication.

**Selection of Materials**

It is well known that the main reason for the failure of rotating parts of machines arise due to the wearing of the moving parts that caused by rubbing of surfaces. It is therefore necessary that moving parts be designed in such a way that the friction and wear are less. This can be ascertained by choosing newer materials which are wear resistant and testing them in a real operating environment or in simulated in laboratories tests.

It is now well established that non-metallic materials are suitable options for the manufacture of bearings. They are generally preferred in operating environments where

1. The lubricant is inadequate combined with high loads and at low speeds,
2. Intermittent motion making lubrication difficult,
3. Problem of contamination of lubricants with the presence of solid or liquid contaminants.
A key parameter for material selection is their wear performance in conditions where there is no lubrication of polymer composites used in mechanical components[9] such type of components can be used in various types of wear situations. The selection of material is based on their longevity and lower friction losses.

**Material Composition**

In this investigation, hybrid composite journal bearings made of glass/epoxy laminated composites were prepared and tested under various conditions and compared with journal bearing made of gun metal. The material composition for the composite journal bearing is shown in Table 2

**Table 2: Material composition for the composite journal bearing.**

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Designation of Material</th>
<th>Biaxial E-Glass Fibre (wt %)</th>
<th>Epoxy (wt %)</th>
<th>Filler Materials (wt %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>GE</td>
<td>35</td>
<td>65</td>
<td>Nil</td>
</tr>
<tr>
<td>3</td>
<td>GEA₂S₂</td>
<td>35</td>
<td>44</td>
<td>1% SiC+20% Al₂O₃</td>
</tr>
</tbody>
</table>

**Table 3: Properties of Aluminium oxide and Silicon carbide.**

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Properties</th>
<th>Aluminium oxide</th>
<th>Silicon carbide</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tensile strength (MPa)</td>
<td>416</td>
<td>588</td>
</tr>
<tr>
<td>2</td>
<td>Density (gm/cm³)</td>
<td>3.98</td>
<td>3.30</td>
</tr>
<tr>
<td>3</td>
<td>Coefficient of thermal expansion (10⁻⁶/°C)</td>
<td>7.4</td>
<td>4.6</td>
</tr>
</tbody>
</table>

The following procedure was adopted to prepare the journal bearing specimens:

The E-glass/Epoxy based composites mixed with varying concentrations were prepared. Fabrication of the composites is done at room temperature using hand layup techniques. The required ingredients of resin, hardener, and fillers were mixed thoroughly in a basin. The glass fibre was positioned manually and the mixture was poured into the mould cavity. The entrapped air was removed manually with squeezes or rollers to complete the bearing specimen and the composite was cured at room temperature.

Steps for the preparation of composite bearing:

**Step 1**: Apply the oil upper and lower surface of the tool (releasing agent).

**Step 2**: Cut the E-glass 300GSM as per tool. (8 Numbers)

**Step 3**: Mix the Resin LY556: Hardener HY 951: Aluminium oxide and Silicon carbide

**Step 4**: Wet the first layer and layup in to female tool and follow the same till the 8th layer is applied.

**Step 5**: Fix the male tool with the female and clamp it tightly.

**Step 6**: Allow for room temperature curing for 12 hours.

**Step 7**: Post cure the model with the tool at 100 degree Celsius in a hot air oven.
Step 8: Remove the model from the tool and trim the edges and clear as per the original model or drawing.

**Figure 1:** GlassFiber + Epoxy + Aluminium oxide + Silicon carbide Journal Bearing.

4. **Surface Roughness Test**

The surface roughness tester is a multi-application measuring instrument for the evaluation of the component surface quality. It is capable of testing the surface roughness of the plane, cylinder, groove and bearing raceway. The surface roughness of the material plays a major role in the tribological characteristics of the journal bearing. The operating surface of the sleeve is made up of glass fibre/Al₂O₃/SiC with epoxy resin. The bearing sleeve was tested before and after the dry run test with a MarSurf GD120 surface roughness tester as shown in Figure 2. The ISO, JIS, ASME (N+2xLC) standards were followed with the length of 5.60mm, measuring speed of 0.5 mm/s and measuring intervals of 0.5μm.

**Figure 2:** Surface roughness tester.

5. **Roughness Parameters**

The evaluation of the surface roughness is very important for causing many fundamental problems such as friction, contact deformation, heat, tightness of contact joints and positional accuracy. In this study, the roughness parameters were measured in the bearing before and after the dry sliding test. The negative change in surface roughness plots indicated the smoothening effect after the test.
A number of surface roughness parameters were used including the arithmetic mean height ($R_a$), root mean square roughness ($R_q$), maximum valley to peak excursion ($R_t$) or maximum height of profile to assess the surface roughness of the journal bearing.

(i) Arithmetic average height ($R_a$)

The arithmetic average height parameter, also known as the centre line average is the most universally used roughness parameter for quality control. It is the average absolute deviation of the roughness irregularities from the mean line over one sampling length. This parameter gives a good description of the variations in heights. Figure 3 shows arithmetic average height $R_a$.

![Figure 3: Arithmetic average height ($R_a$).](image)

(ii) Root Mean Square Roughness ($R_q$)

This parameter is also known as the Root Mean Square (RMS). It represents the standard deviation of the distribution of the surface heights, so it is an important parameter to describe the surface roughness. This parameter is more sensitive than the arithmetic average height ($R_a$) and it varies from the mean line with large deviation. The RMS mean line is the line that divides the profile so that the sum of the squares of the deviations of the profile height from it is equal to zero.

(iii) Maximum height of the profile $R_t$ or $R_{max}$

This parameter is very sensitive to measure maximum roughness in deep scratches of the specimen. It is the vertical distance between highest peak and the lowest valley along the assessment of the profile.

(iv) Maximum height of peaks ($R_p$)

$R_p$ is the maximum height of the profile above the mean line within the assessment length.

(v) Maximum depth of valleys ($R_v$)

It is defined as the maximum depth of the profile below the mean line within the assessment length.
(vi) **Skewness (Rsk)**

It is used to measure the symmetry of the profile about the mean line. This parameter is sensitive to occasional deep valleys or high peaks. A symmetrical height distribution with as many peaks as valleys exhibits zero skewness. The profiles with peaks removed or with deep scratches exhibit a negative skewness. Profiles with valleys filled in or high peaks exhibit positive skewness. This parameter is used to distinguish between two profiles having the same Ra or Rq values but with different shapes.

(vii) **Ten point height (Rz)**

This parameter is more sensitive to occasional high peaks or deep valleys than Ra. This parameter defines the difference in height between the average of the five highest peaks and the five lowest valleys along the assessment length of the profile.

6. **Results and Discussion**

**Locations of surface roughness in the journal bearing**

The roughness was measured at different locations on the bearing surface before the tests by choosing locations circumferentially as shown in Figure 4.29 and Figure 4.30. It was often difficult to select a location as a true representative of the worn surface, because in the test samples some times the roughness within the worn area varied drastically from one location to another.

![Figure 4: Locations of surface roughness in the journal bearing.](image)

It was investigated and found that in dynamic conditions the wear process is uneven and variation in the maximum shear stresses occurred in the circumferential direction. This is due to the coefficient of friction fluctuating during the sliding wear process and is a function of compressive stress, while compressive stress is a function of load on bearing and the revolution speed of the shaft.

The measurement locations were chosen circumferentially to the bearing and a minimum of three measurements were considered to assess the roughness of the bearing in the worn out area.
The following procedure was adopted to prepare the journal bearing specimens:

The E-glass /Epoxy based composites mixed with varying concentrations (0, 10 and 20 wt %) of silicon carbide (SiC) and aluminium oxide (Al₂O₃), were prepared. Fabrication of the composites is done at room temperature using hand layup techniques. The required ingredients of resin, hardener, and fillers were mixed thoroughly in a basin. The glass fibrewas positioned manually and the mixture was poured into the mould cavity. The entrapped air was removed manually with squeezes or rollers to complete the bearing specimen and the composite was cured at room temperature.

(i) Roughness Parameters for Composite Journal Bearings

The results of surface roughness for the various bearings is shown below. The surface roughness was measured prior to the running of the shaft and after the wear test.

Figure 4 and Figure 5 show the surface roughness of GEA₂S₂ after the dry test at locations 2 and 3. The results shows that Rₜ of GEA₂S₂ has decreased after the dry test when compared to GE epoxy bearing by 26.96% and 70.76% at the bearing location 2 and location 3 respectively. Thus, an average surface roughness of 48.96% got reduced after the dry test in GEA₂S₂. According to the expectations of the values of the roughness parameters Rₐ and Rₜ have decreased.

Figure 6 Glass fibre epoxy+SiC+Al₂O₃ bearing (GEA₂S₂)before the dry test at location-1.

Ra = 0.4661 µm;  Rq =0.6024 µm;  Rz = 3,1041 µm;
Rmax = 4,0767µm;  Rt =4.1802 µm;  Rp=1.7214µm;
Rᵥ=1.3827µm;  Rₛₘ=159.5217µm;  Rs=69.4998 µm;
Rₛₖ= 0.671µm
Root Mean Square Roughness (Rq) represents the standard deviation of the distribution of the surface heights, so it is an important parameter to describe the surface roughness. This parameter is more sensitive to large deviation from the mean line than the arithmetic average height (Ra). The RMS value of the of the assessed profile has decreased about 43.7% and 41.9% after the dry test in the GEA₂S₂ bearing at the bearing location 2 and location 3 respectively when compared to the GE bearing.

From the results it can be seen that the GE bearing has an increased value of Ra, Rq and Rt after the dry test because of increased coefficient of friction at the fibre edges. Further, the GE bearing does not facilitate the formation of a film between the shaft and the bearing during the dry sliding test.
Figure 9: Glass fibre epoxy+SiC+Al₂O₃ bearing (GEA₂S₂) after the dry test at location 2

\[
\begin{align*}
Ra &= 0.5078 \, \mu m; & Rq &= 0.6928 \, \mu m; & Rz &= 4.3979 \, \mu m; \\
R_{max} &= 7.5944 \, \mu m; & R_t &= 7.5944 \, \mu m; & R_p &= 1.3622 \, \mu m; \\
R_s &= 3.0357 \, \mu m; & R_{S_m} &= 118.0000 \, \mu m; & R_s &= 96.2870 \, \mu m; \\
R_{sk} &= -1.543 \, \mu m
\end{align*}
\]

The average surface roughness of Glass fibre epoxy+SiC+20% Al₂O₃(GEA₂S₂) journal bearing got reduced i.e., Ra = 0.5078 and Ra = 0.4580 after the dry sliding test at location 2 and location 3 respectively. This is due to the large asperities of the composite surface being abraded by the hard steel surface of the journal during the test. After this period, the friction coefficient decreased. This was because there was contact between the steel shaft and the epoxy resin containing aluminium oxide and silicon carbide powder. Al₂O₃ +SiC particles got removed and formed a transfer lubricating film on the metal.

Figure 10: Glass fibre epoxy+SiC+Al₂O₃ bearing (GEA₂S₂) before the dry test at location 3

\[
\begin{align*}
Ra &= 0.6240 \, \mu m; & Rq &= 0.8183 \, \mu m; & Rz &= 5.0733 \, \mu m; \\
R_{max} &= 9.5448 \, \mu m; & R_t &= 9.5448 \, \mu m; & R_p &= 1.9856 \, \mu m; \\
R_s &= 3.0878 \, \mu m; & R_{S_m} &= 96.4875 \, \mu m; & R_s &= 79.6908 \, \mu m; \\
R_{sk} &= -0.443 \, \mu m
\end{align*}
\]

After the dry test the GEA₂S₂ bearing shows that the worn surface was quickly polished to the mirror like surface and the wear debris was rapidly squeezed into the worn surface, which cause the reduced friction coefficient of the composites at the high sliding speed. There were small scoring marks on the surface of the journal after the dry test. No critical damage was observed on the composite bearing surface, where a continuous film of wear debris was found on the wear track.
Figure 11: Glass fibre epoxy+SiC+Al₂O₃ bearing (GEA₂S₂) after the dry test at location-3.

Ra = 0.4580 µm;  \( R_q = 0.6063 \mu m; \)  \( R_z = 3.0943 \mu m; \)

Rmax=4.2250µm;  \( R_t = 4.2250 \mu m; \)  \( R_p = 1.3688 \mu m; \)

Rv=1.7254µm;   \( R_{Sm} = 117.2879 \mu m; \)  \( R_s = 63.6965 \mu m; \)

Rsk= -0.027 µm

Thus, the results show that the surface roughness of the Glass fibre epoxy+SiC+ 20% Al₂O₃(GEA₂S₂)journal bearing decreased after the dry test when compared to the GE epoxy bearing by 42.56% and 26.96% at the bearing location 2 and location 3 respectively. In the beginning, wear occurred rapidly because the shaft surface was not covered completely by the Al₂O₃ and SiC composite layer. The wear became stable faster than the friction coefficient because Al₂O₃ and SiC composite film on the shaft surface which was effective in controlling the friction was not formed continuously.

The formation of Al₂O₃ and SiC composite film on the shaft surface occurred because the adhesion force between the first composite wear products and steel shaft is greater than the cohesion force between first composite wear products and bearing surface.

Another possible reason for the increase of film thickness could be the greater cohesion force between the new composite wear products and the first composite film on shaft surface than the cohesion force between the new composite wear products and composite film on bearing surface. So, new composite wear products make the formation of thick film on the shaft surface. It is a natural result that there is an increase of film thickness which becomes continuous during the run in time.

(ii) Roughness Parameters for Gun Metal Journal Bearing

Figure 12 shows the surface roughness of gun metal bearing before the dry run test at location-1.

Ra = 0.8787 µm;  \( R_q = 1.1594 \mu m; \)  \( R_z = 5.3192 \mu m; \)

Rmax=6.6546µm;  \( R_t = 6.9038 \mu m; \)  \( R_p = 1.9139 \mu m; \)

Rv=3.4053µm;   \( R_{Sm} = 166.5455 \mu m; \)  \( R_s = 17.8160 \mu m; \)

Rsk= -1.206 µm

Figure 12 shows the surface roughness of gun metal bearing before the dry run test at location 1. The average roughness is Ra= 0.8787. Figure 13 shows the surface roughness of gun metal bearing after the dry run test at location
The average roughness is Ra = 4.6848. Since the ends (location 1) of the gun metal bearing are not prone to accumulate film on the bearing surface. Hence, (at location 1) after the dry test, the surface roughness was more, when compared to location 2 and location 3.

Figure 13: Gun metal bearing after the dry test at location-1

Ra = 4.6848 \mu m; \quad Rq = 8.3866 \mu m; \quad Rz = 27.9539 \mu m;
Rmax=62.3556\mu m; \quad Rt=62.3556 \mu m; \quad Rp=9.2780\mu m;
Rv=18.6759\mu m; \quad R_{Sm}=733.6250\mu m; \quad Rs=450.1991 \mu m;
Rsk= -1.599 \mu m

Figure 14: Gun metal bearing before the dry test at location-2

Ra = 7.5728 \mu m; \quad Rq = 11.5928 \mu m; \quad Rz = 78.1981 \mu m;
Rmax=75.2601\mu m; \quad Rt=75.2601 \mu m; \quad Rp=15.6783\mu m;
Rv=22,5198\mu m; \quad R_{Sm}=461.7500\mu m; \quad Rs=218.3508\mu m;
Rsk= -0.996 \mu m;

It was found that after the dry run test the values of roughness parameters were decreased because of formation of oxide film in the composite journal bearing.

However the formation of asperities in the composite bearing is less than that of the gun metal bearing. In the gun metal bearing, due to the absence of oil and increased friction coefficient, much strain on the bearing is caused. Further, the continuous metal to metal contact between the journal and the bearing leads to an increase in the temperature. So, that corrosion and followed by erosion took place.
Figure 15: Gun metal bearing after the dry test at location 2

Ra = 1.2587 µm;  \quad Rq = 1.6336 µm;  \quad Rz = 7.4357 µm;
Rmax = 9.6659 µm;  \quad Rt = 10.2317 µm;  \quad Rp = 2.4513 µm;
Rv = 4.9844 µm;  \quad Rsm = 212.1765 µm;  \quad Rs = 128.1540 µm;
Rsk = -0.994 µm

Figure 15 and 17 show the surface roughness of the gun metal bearing after the dry run test at location 2 and location 3. The average roughness are Ra = 1.2587 and Ra = 0.5719. According to the expectations of the values of the roughness parameter Rₐ and Rₜ have decreased.

Gun metal bearing wears more and this may lead to more debris being formed, contributing to a higher friction coefficient than that of the composite bearing combination. The asperity contact carries most of the load in boundary lubrication, so the surfaces of the bearing are easily worn in this regime.

Figure 16: Gun metal bearing before the dry test at location 3.

Ra = 7.4711 µm;  \quad Rq = 11.7044 µm;  \quad Rz = 38.2610 µm;
Rmax = 76.5425 µm;  \quad Rt = 76,5425 µm;  \quad Rp = 16.6444 µm;
Rv = 21.6165 µm;  \quad Rsm = 413.1667 µm;  \quad Rs = 219.1156 µm;
Rsk = -1.105 µm

Figure 17: Gun metal bearing after the dry run test location 3.

Ra = 0.5719 µm;  \quad Rq = 0.8232 µm;  \quad Rz = 4.2228 µm;
Rmax = 5.7743 µm;  \quad Rt = 5.9545 µm;  \quad Rp = 1.0940 µm;
Rv = 3.1228 µm;  \quad Rsm = 175.5476 µm;  \quad Rs = 131.6090 µm;
Rsk = -2.057 µm

The presence of debris between the contact surfaces enhanced the surface roughness to some extent in an indirect way, resulting in a transiently lower the film formation. Hence, the gun metal bearing was easily worn out and produced more wear particles.
Conclusion

For the gun metal, the results showed that after the dry run test a value of average roughness and maximum roughness height increased due to continuous metal to metal contact between the journal and the bearing. From the results, it can be seen that when compared to gun metal bearing the composite journal bearing (GEA₂S₂) has less surface roughness value and there is a clear indication that the composite possesses very good tribological characteristics.

References


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