Fretting Wear Failures In Bearing Steel EN31 Mated Against Structural Steel EN 24

R Ramesh and R Gnanamoorthy

Department of Mechanical Engineering
Indian Institute of Technology Madras
CHENNAI 600 036

ABSTRACT

Bearings fitted in the machines and automobiles experience fretting action due to machine vibration and other external forces during service. Fretting is a form of surface damage encountered in the machine components which experience small oscillatory movements. An attempt is made to understand fretting in bearing steels. A fretting wear test machine is designed and developed as a part of the current research program. The friction force, slip amplitude and frequency are continuously measured and recorded using the computer controlled data acquisition system. Fretting wear behavior of the commonly used structural steel En 24 in the as received and hardened-tempered condition mated with the hardened-tempered bearing steel En 31 are reported. The coefficient of friction increased drastically during the early stages of fretting due to the oxide layer contact and breaking of the oxide layer. Hardening plays only a marginal role in improving the fretting wear in the test conditions investigated.

INTRODUCTION

Small relative motion of the order of few tens of microns normally encountered many joints in machineries is termed as fretting. The fretting wear was frequently observed in keys, splines, bearing inner race and shaft, bearing outer race and housing, multiplayer leaf springs, lugs, hub and shaft, pinned joints, flanges, turbine blade roots, blotted and riveted joints etc. More than fifty parameters are found to affect the fretting fatigue and fretting wear characteristics [1-3]. Slip amplitude, normal force, number of fretting cycles, environment, and lubrication are few of the important parameters that are investigated by researchers to study their effects on fretting wear characteristics [1-3]. Fretting wear studies were carried out in different types of test apparatus, as there is no standard test methodology proposed. High frequency fretting tests were conducted using the piezo electric type drives [4]. The servo hydraulic fatigue test machines were also used for fretting wear studies. Fretting wear characteristics of steels [5-6], aluminium
alloys [7], titanium alloys [7] were reported. Effect of heat treatment [8] and coatings [9] are also investigated by many researchers.

In rolling element-bearing assembly, the inner race and outer race experience severe fretting wear damage. Understanding and improving the fretting wear behavior is important to increase the bearing life and avoid catastrophic failures in service. The widely used structural steel, En 24, is fretted with the bearing steel, En 31 during the present studies. The medium strength alloy steel, En 24, is normally used in as received condition or in the through hardened and tempered condition. In this paper the fretting wear behavior of as-received and hardened-tempered structural steel En 24 when fretted with the hardened and tempered bearing steel, En 31 is reported.

**TEST DETAILS**

**Fretting Wear Test Machine**

Fretting wear studies were conducted in the laboratory developed fretting wear test rig. A schematic diagram of the experimental apparatus is illustrated in Fig. 1. The test rig permits fretting tests with different slip amplitudes ranging from 10 to 200 microns and test frequencies up to 30 Hz. Crossed cylinder geometry, which results in point contact, was used for the tests. Details of the test rig are described elsewhere [8]. The test rig consists of lower moving specimen holder and upper stationary counter specimen holder, in which test specimens are fixed. The tangential force between the specimens is measured by a force transducer. For measuring displacement of fretting specimen a laser optical displacement sensor is used. The frictional forces, slip amplitude and frequency are continuously measured and recorded using a computer controlled data acquisition system.

**Test Materials and Experimental Procedure**

The medium strength alloy steel, En 24, available in the rod form is turned and ground to the required dimensions. Fretting wear tests were conducted in the as-received and hardened-tempered conditions. Hardening and tempering was carried out at 1118 K followed by tempering at 853 K for 1 h. Hardening of bearing steel was carried out at 1133 K for 15 minutes followed by quenching in water medium kept below 323 K. Tempering was carried out at 423 K for one hour and thirty minutes. Hardened specimens were ground to required dimensions and surface finish.

Prior to testing all specimens were ultrasonically cleaned in acetone. Required displacement amplitude of the specimen was set by adjusting the eccentric unit. Tests were carried out at constant slip amplitude of 60 µm for the current investigation.
Specimens were mounted rigidly in the specimen holder to avoid any slip during test. Fretting wear tests were carried out under un lubricated condition at room temperature. Tests were conducted at five different normal loads ranging from 2.4 N to 29.4 N. At least two tests were conducted in each condition.

Fig. 1. Schematic of the fretting wear test rig used in the current studies.

Table 1. Test condition, hardness and surface roughness of the test materials

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Specimens</th>
<th>Condition</th>
<th>Hardness (HV)</th>
<th>Rₐ (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>En 24</td>
<td>As Received</td>
<td>207</td>
<td>0.65</td>
</tr>
</tbody>
</table>
Frictional force and displacement of specimens were measured continuously throughout the test at periodic intervals. The data were acquired at a sample rate of 150 samples per second. Wear volume loss (V) was calculated from wear scar diameter using the approximate equation given by Halling [10]

$$v = \pi R h^2 \left(1 - \frac{h}{4R}\right)^4$$  \hspace{1cm} -- Eq. (1)

where R is the radius of the cylindrical specimens and h, is the maximum depth of the wear scar. The value of maximum depth of the wear scar, h, is related to measured mean wear scar diameter by following equation

$$h = R - \left(R^2 - \frac{d^2}{4}\right)^{\frac{1}{2}}$$ \hspace{1cm} --Eq.(2)

where d is the mean wear scar diameter. An average of at least four measured wear scar diameter values was used for the calculating the wear scar depth.

RESULT AND DISCUSSION

Friction Behavior under Fretting Conditions

The friction coefficient values were estimated by calculating the ratio of measured frictional force to applied normal force ($F_n$). Typical variation of the coefficient of friction during the testing is shown in Figure 2 (a) and (b) for two different normal loads, 2.4N and 29.4N, respectively. At the beginning of test, the friction coefficient is low, about 0.55, and it rises to about 0.7 – 0.8 in a short period. All the experiments showed the steady state coefficient of friction regime irrespective of the treatment or normal force. During the initial contact, presence of thin oxide layer in steel specimens reduces the friction and after few tens of cycle the oxide layer breaks down and corresponds to the establishment of steel to steel contact leading to increase in friction.

Figure 3 shows the steady state coefficient of friction for the test materials at different loads. The steady state coefficient of friction values varied between 0.85 and 0.65 at different normal loads. Waterhouse [11] showed that adhesion is the strongest at slip amplitude of 70 µm and decreased as the slip amplitude increases. During the current investigations, the slip amplitude is 60µm and therefore adhesion is expected to play a dominant role leading to high coefficient of friction. Increasing normal load, the coefficient of friction decreases for both as received and heat-treated steels. The as received En24 steel specimens exhibit a marginally higher coefficient of friction.
compared with the hardened and tempered En 24 steel at light loads. The effect hardness of mating materials influences the real area of contact. The real area of contact is smaller for through hardened steel pair resulting in lower adhesion and consequently the less coefficient of friction at light loads. At higher loads, 29.4 N, the coefficient of friction of the hardened material is higher compared with the as received material unlike the behavior at the low loads. This is discussed in detail in the later section.

Fig. 2. Variation of coefficient of friction during testing for a normal force of (a) 2.4N and (b) 29.4N.
Fig. 3. Steady state coefficient of friction values at different normal loads.

Fretting Wear

The average wear scar diameter measured using the optical microscope is used for calculating the fretting wears loss. Fretting wear scar diameter increases with increasing normal applied load up to a particular load and goes down for further loading. The wear loss due to fretting increases with increasing normal applied load up to a particular load. However, with further increasing, the wear loss decreases. Under identical test conditions, the wear volume for the as received and hardened and tempered steels are nearly same. No significant improvement in the wear resistance could be observed during fretting action unlike conventional sliding wear. Studies conducted by Kayba et al [10] also indicate a minor influence of hardening on fretting wear resistance. The fretting wear is dependent on the presence of oxidized hard debris and not much on hardness. Under light loads, the slip is spread over the entire contact area and causes oxidation assisted wear damage. With increase in load from 2.4 to 9.8 N, the as received and through hardened En24 steel shows increased wear loss. At higher loads, the wear loss decreases.

According to Mindlins theory of elastic contacts, under tangential loading a slip annulus and stick zone are obtained at the contact surfaces [11]. At high normal load, the center of the contact remains locked and slip at the boundary of contact area exist. Under this condition through hardened steel pair causes severe damage than as received steel. During fretting hardened surface and counter surface produces hard wear particles which
were trapped at the contact area due to low slip. Abrasion was found to be a dominant mechanism, which causes severe wear, locally, at the slip zone.

![Graph showing wear volume as a function of normal load under fretting conditions.]

Fig. 4. Wear volume as a function of normal load under fretting conditions.

**CONCLUSION**

Fretting wear characteristics of the as received and through hardened structural steel, En24 against hardened and tempered bearing steel, En31 was investigated using the developed fretting wear test machine. High coefficient of friction was exhibited under fretting conditions for the as received and hardened materials. The coefficient of friction decreased with increasing normal load for both as received and through hardened material. No significant effect on fretting wear resistance due hardening was observed indicating negligible effect of hardening.

**ACKNOWLEDGMENTS**

Authors are thankful for the various help provided by Mr S Senthil velan, Mr G Srinath and Mr S Shivaraj during the project work.
REFERENCES

8. Ramesh. R, and Gnanamoorthy. R, Fretting wear behavior of liquid nitrided En24 steel fretted with the hardened En 31 bearing steel, Accepted for presentation in the International Conference on Surface Treatments to be held at Hyderabad, November 2004.