Track or Category
Rolling Element Bearings III (Session 6A)

Structure Change of Cementite just below the Sliding Surface on Ball Bearings

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ABSTRACT

Many ball bearings have widely been made with SUJ2 (high carbon chromium bearing steel). The material maintains its hardness by the precipitation of cementite. By the observation of the subsurface below rotating race using TEM (transmission electron microscope), we found the distortion and the fracture of cementite bands after the bearing operation under the half of the dynamic load capacity. The damaged cementite bands were cracked easily and consequently expected to promote wear. Because the phenomenon greatly affects bearing life, we would like to report and discuss these TEM images.

KEYWORDS

Surfaces: TEM, Rolling Bearings: Ball Bearings, Wear: Wear Mechanisms.

INTRODUCTION

Lifetime estimation required a large number of tests that took a long time(1)(2). The latest procedure to calculate the lifetime curve is a product of the lifetime characteristics from materials testing, the lifetime curve of the bearings, and a linkage coefficient(3). This method allows lifetime curve estimation with high precision. The time necessary to obtain the lifetime curve has become shorter compared to testing methods using bearings only, but still a lot of materials testing is required.

Materials after useful lifetime show a characteristic change in the metallographic structure namely slip bands aligned at an angle. We thought that the number of tests needed to obtain the lifetime curve could be decreased by detecting this change in the metallographic structure in a much shorter testing time. Therefore, we conducted bearing tests over a duration where external observation could not find any damage or wear on the rolling contact surface. Subsequently, the inner races of the bearings were observed in detail using TEM. We propose a method to estimate the bearing lifetime by capturing signs of change in the fine crystal grains immediately below the rolling contact surface.

Test method (Bearing test)

Bearing tests were conducted with a proprietary testing machine where an arbitrary pressure waveform can be applied. A schematic of the bearing testing machine is shown in Figure 1. Lubricant oil was supplied to the test bearing along the rotation axis. Honda 11 ATF was used as the lubricant oil, and its temperature was set to 80˚C, which is the temperature in actual driving conditions.

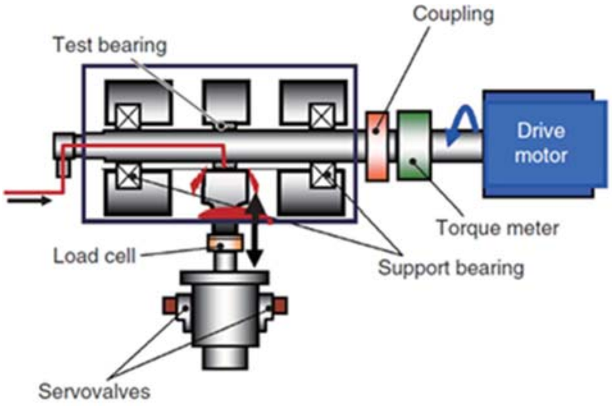


Figure 1. Schematic of bearing testing machine.

Figure 2 shows the load profile and the direction of load in bearing tests. Static load corresponds to conditions (1, 5, 6), and conditions (2, 3, 4) indicate dynamic load. The dynamic load was limited to within ± 0.6 kN from the average.

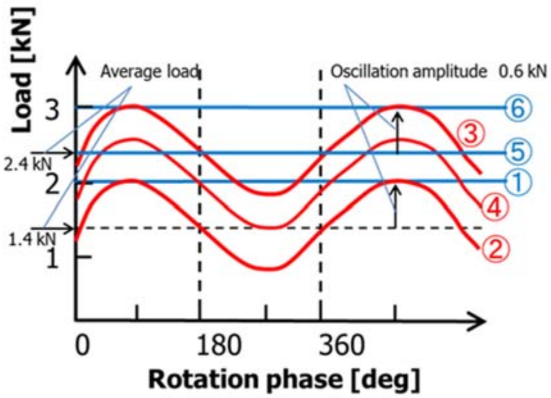


Figure 2. Load profile in bearing tests.

Test method (Experimental method)

After a bearing test, TEM specimens were fabricated by cutting out the center of the rolling contact surface of the bearing inner race and then using a focused ion beam (FIB). Figure 3 shows the fabrication process (1 → 2 → 3 → 4). Panel 4 is the specimen for TEM observation. FIB was carried out using nanoDUE'T® NB5000 (Hitachi High-Technologies) and TEM was performed using JEM-2800 (JEOL).

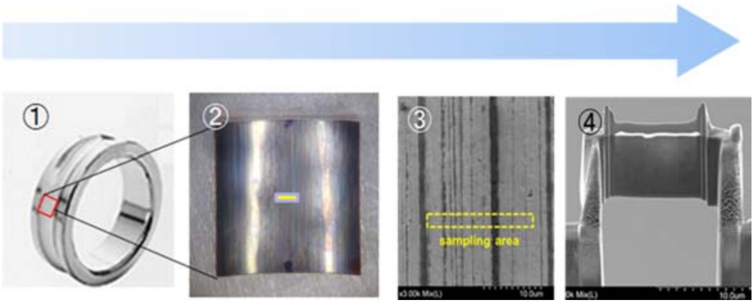
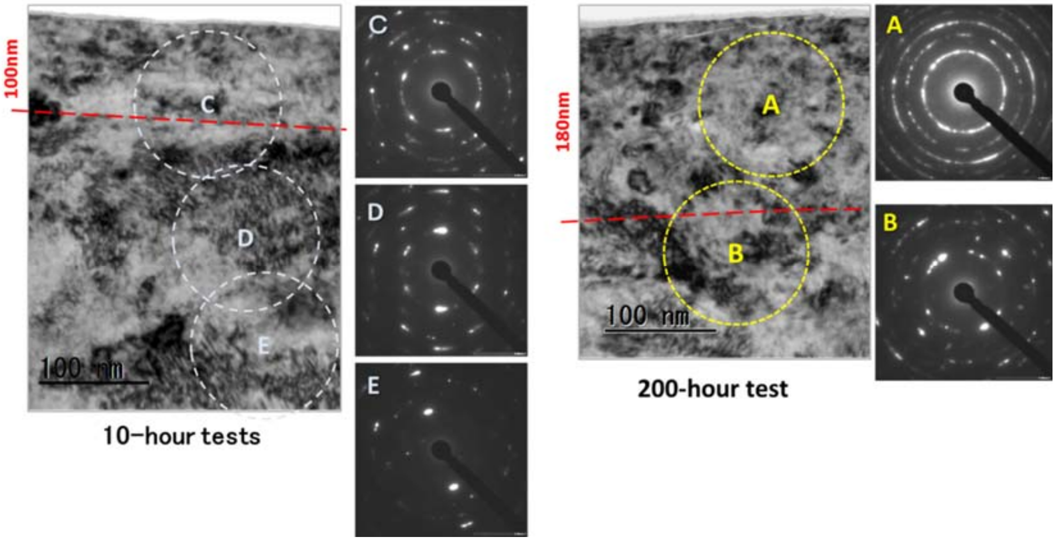


Figure 3. TEM specimen fabrication process.

Result (Long-term tests with static and dynamic load)

Long-term tests are important in lifetime estimation of bearings, therefore a 200-hour test was conducted and compared with 10-hour tests under various conditions. Figure 4 shows a comparison of TEM images between the long-term (200-hour) test and various 10-hour tests.



10−hour tests

200-hour test

Figure 4. Comparison of TEM images of test bearing specimens after the long-term (200-hour) test and 10-hour tests.

The fine crystal layer grew over a thicker layer under static load compared to under dynamic load because the time that the load is within a range suitable for fine crystal layer growth at the rolling contact surface is shorter under dynamic load. There was some wear in the 200-hour test because the thickness of the fine crystal layer is the same as the 10-hour test but the surface is lower than the original position. Once a certain thickness of fine crystal layer has formed, wear appears to progress within the layer.

Crystal size is A＜B＝C＜D＜E.

The fine crystal structure from the 200-hour test existed until the same depth before the test, and the fine crystal structure extended deeper, part of the surface peeled off from wear, and twin deformation was found at further depths.(4)

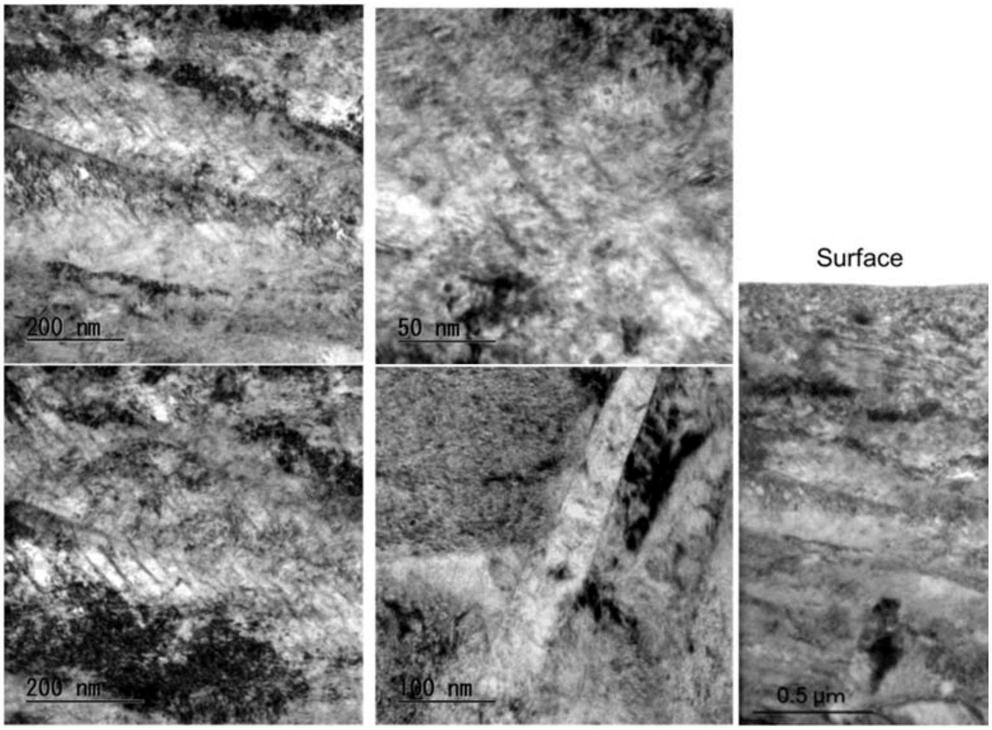


Figure 5. Observation of an area just below the rolling contact surface using a high resolution TEM and a highly magnified enlargement around point B.

Summary

Bearing tests were conducted and the following change in metallographic structure was found at just below the rolling contact surface even though no change was observed on the rolling contact surface.

(1) Under dynamic load, twin deformation happens below the fine crystal layer that form just below the rolling contact surface.

(2) More twin deformation happens with increased test duration when the load is the same. The fine crystal layer that forms just below the rolling contact surface is subject to wear but maintains a certain thickness.

Finally

The number of bearing tests in this study was small and the test time was not very long. However, we found a possibility to estimate the lifetime curve in a short time by focusing on the fine crystal layer that forms just below the rolling contact surface and on how twin deformation under this layer increases.

Future Plan

We will increase the number and duration of tests and conduct further detailed TEM observations to improve the precision.

References

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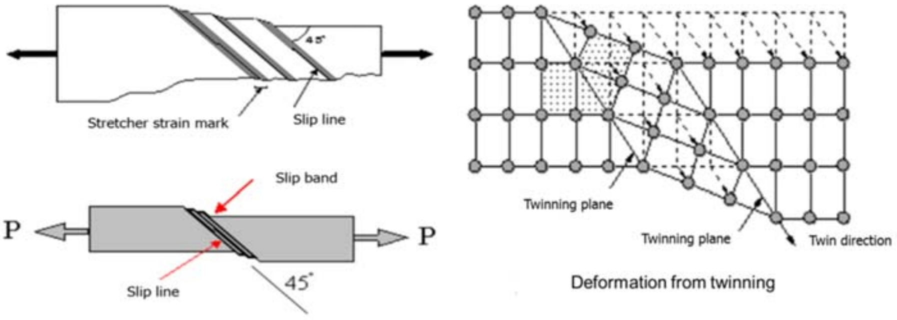
Appendix



Schematic of slip deformation **Deformation from twinning**

Figure 6. Schematic of slip deformation and schematic of twin deformation.

Slip deformation as in left figures happens with structural fatigue. Stretcher strain marks form at an angle of 45° when pulled in the right-left direction, and the material breaks apart along the slip lines. This is caused by twin deformation at the atomic level.

The right figure shows twin deformation. Twin deformation is a slip phenomenon that happens along the twinning plane when some force is applied along the twin direction in a crystal of ordered iron atoms.