Effect of Fine Metal Compounds on Hydrogen Embrittlement Resistance

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We recently developed a bearing steel and a hardening process, in which a large number of fine metal compounds are generated and dispersed on the surface layer of the rolling bearing raceway, to prevent premature failure due to hydrogen embrittlement. In this study, to evaluate hydrogen embrittlement resistance, a rolling contact fatigue test is carried out under various operating conditions. In addition, wear resistance is evaluated and the effect of the fine metal compounds on hydrogen embrittlement resistance is discussed.

Keywords: *rolling bearing, steel, hydrogen embrittlement*

1. Introduction

Under the severe lubrication conditions in various types of industrial and automotive machinery, premature and internally originated flaking failure frequently occurs in rolling bearings. The main cause of such failures is thought to be hydrogen penetration[1)], which is induced by slippage between the rolling contact elements. This slippage causes wear, exposing the nascent and active steel surface. Subsequently, hydrogen atoms are generated by the decomposition of the lubricant and penetrate into the steel[2)]. It is thus important to consider the components and heat treatment conditions of steel to prevent hydrogen generation and penetration. Accordingly, we recently developed a bearing steel and a hardening process to prevent premature failure due to hydrogen embrittlement. In the hardening process, a large number of fine metal compounds are generated and dispersed on the surface layer of the raceway. In this study, a rolling contact fatigue (RCF) test is carried out to evaluate the hydrogen embrittlement resistance of the developed bearing and a conventional bearing. In addition, wear resistance is evaluated and the effect of the fine metal compounds on hydrogen embrittlement resistance is discussed.

2. Materials and methods

To evaluate hydrogen embrittlement resistance, a thrust-type RCF test was carried out under the test conditions shown in Table 1. The developed bearing rings were made from the developed steel (Steel A; JIS-SUJ2 with added vanadium and molybdenum) and the conventional bearing rings were made from JIS-SUJ2. The balls were made from SUS440C. The heat treatment involved a hardening process and a tempering process. The hardening process for the rings was standard quenching or nitriding-quenching, which resulted in the formation of a surface layer with high nitrogen concentration. The hardness of the raceway surfaces of all rings, measured using a Vickers hardness testing machine, was 750±50 HV_{300}.

A metallographic investigation was performed on the cross section of the outer rings. The samples were cut along the circumferential cross section on the raceway surface. The cut samples were hot-mounted in bakelite, ground and polished. The samples were etched in 3% nital solution. The microstructure was examined using optical microscopy and field-emission scanning electron microscopy (FE-SEM). Element intensity maps were obtained using energy-dispersive X-ray spectroscopy to analyze the metal compounds generated in the steel.

Table 1 Conditions used in RCF test.

Test bearing	51106
Ball	1/4” (6.35 mm)
P_{max}	2.3 GPa
Rotation speed	Repeated rapid acceleration / deceleration
Lubricant	Polyglycol oil + pure water

To evaluate wear resistance, an NTN-Savin-type wear test was carried out at room temperature. Figure 1 shows a schematic diagram of the test rig and Table 2 shows the test conditions. The test specimens were plate-shaped and had dimensions of 15 × 6 × 3 mm³. A rotating circular plate made from JIS-SUJ2 with standard quenching and tempering was used as the counter material.

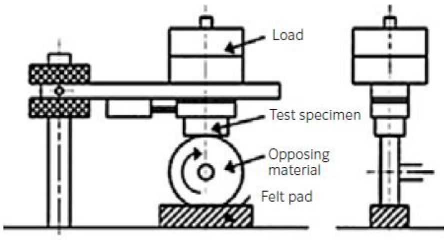

Figure 1 Schematic diagram of NTN-Savin-type wear test rig.

Table 2 Conditions used in wear test.

Load	50 N
P_{max}	0.5 GPa
Sliding speed	0.05 m/s
Sliding time	3600 s
Lubrication oil viscosity grade	ISO VG 2
Opposing material diameter	40 mm
Opposing material sub-curvature	R 60
Opposing material surface roughness	Ra 0.01 μm

3. Results

3.1 RCF life

Figure 2 shows the results of the RCF test. Bearings made from JIS-SUJ2 with nitriding-quenching had a longer service life than that of bearings made from the same material but with standard quenching (through-hardened JIS-SUJ2). The bearings made from Steel A with nitriding-quenching had a service life more than three times longer than that of the through-hardened JIS-SUJ2 bearings.

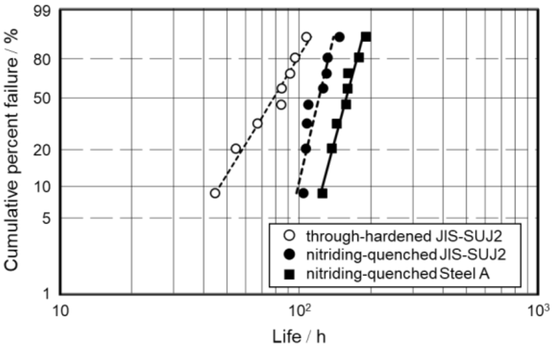

Figure 2 Results of RCF test.

3.2 Microstructure of specimens

Figure 3 shows optical micrographs of the raceway surfaces of heat-treated samples. Among the samples with nitriding-quenching, the bearing made from Steel A had a large number of fine metal compounds dispersed on the raceway surface. Figure 4 shows FE-SEM images of the raceway surface and the corresponding element distribution. Vanadium was enriched in the fine metal compounds of the nitriding-quenched Steel A.

Figure 5 shows cross-sectional observations of the raceway surface after the RCF test. The characteristic microstructural changes associated with hydrogen embrittlement were suppressed in the bearings with nitriding-quenching, whereas white etching cracks were observed in the through-hardened JIS-SUJ2 bearings.

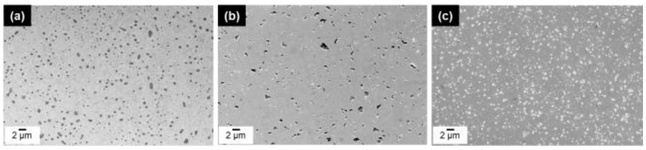

Figure 3 FE-SEM images of raceway surfaces for (a) through-hardened JIS-SUJ2, (b) nitriding-quenched JIS-SUJ2, and (c) nitriding-quenched Steel A.

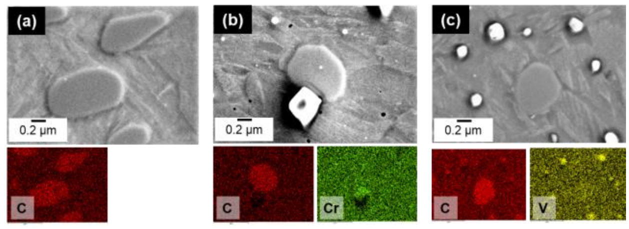

Figure 4 FE-SEM images and element intensity maps of metal compounds on raceway surface for (a) through-hardened JIS-SUJ2, (b) nitriding-quenched JIS-SUJ2, and (c) nitriding-quenched Steel A.

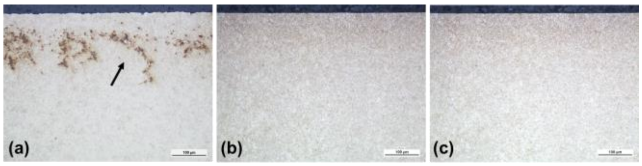

Figure 5 Cross-section optical micrographs of tested specimens in flaking-free area: (a) through-hardened JIS-SUJ2 at 44 h, (b) nitriding-quenched JIS-SUJ2 at 107 h, and (c) nitriding-quenched Steel A at 107 h.

3.3 Wear resistance

Table 3 shows the specific wear rates. The rate for the through-hardened JIS-SUJ2 sample is 28-fold higher than those for the samples with nitriding-quenching. This shows that nitriding-quenching effectively improves wear resistance.

Table 3 Specific wear rate of specimens.

	Specific wear rate ×10^{-10} $mm^3/(N・m)$
Through-hardened JIS-SUJ2	1400
Nitriding-quenched JIS-SUJ2	50
Nitriding-quenched Steel A	50

4. Discussion

Two effects increased the hydrogen embrittlement resistance of bearings made from Steel A with nitriding-quenching. First, the raceway surface with dispersed metal compounds is relatively resistant to wear under severe lubrication conditions. Second, even though hydrogen atoms are generated, the metal compounds suppress the rate of hydrogen penetration into the stress field[3,4] in the rolling contact elements.

5. Conclusions

The nitriding-quenching process generates dispersed metal compounds that extend RCF life and improve wear resistance. The combination of the developed steel (JIS-SUJ2 with added vanadium and molybdenum) and nitriding-quenching creates fine metal compounds composed of vanadium. These compounds improve hydrogen embrittlement resistance.

References

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