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Hydrogen permeation into bearing steels under sliding

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ABSTRACT – This paper describes studies on hydrogen uptake under sliding contact. Sliding tests were conducted with 52100 steel and 440C stainless steel in hydrogen and in vacuum, with and without a lubricant. Hydrogen dissolved in the specimens after sliding were analyzed with thermal desorption spectroscopy (TDS). Hydrogen content increased by sliding, suggesting that dissociation of hydrogen and the oil occurred by the catalytic action at sliding surfaces. The TDS spectrum indicated that the hydrogen dissolved was diffusible hydrogen. It was also found that hydrogen uptake appeared to decrease after the early stage of sliding. Another series of tests were made with heat-treated steel specimens. It was shown that TDS spectrum changed with annealing, which suggested that the hydrogen originally contained the steels was eliminated and trap sites for hydrogen changed. The decomposition of hydrogen and lubricant molecules, and the effect of oxide films at the surfaces on hydrogen uptake are discussed.

1. INTRODUCTION

Hydrogen induced surface failure in rolling element bearings is one of the most important problems in tribology. It is generally accepted that, in oil lubricated conditions, hydrogen is produced through the decomposition of lubricants at fresh steel surfaces, and is diffused in the atomic form into steel to cause crystallographic changes in steel under cyclic loading. However, the relationships between these processes, and those with chemical reactions including oxidation and reduction at the interface, are still not fully understood. Also, there is little knowledge about the conditions where hydrogen is present as surrounding gas. The authors have conducted simple contact experiments and showed that hydrogen concentration in subsurface increased under cyclic normal load [1], and that addition of sliding between the surfaces retards hydrogen permeation with oxide film formation [2].

This study aims to know details of hydrogen permeation in various conditions, the behaviour of the lubricating oil, and the effects of pre-heat treatment on the behaviour of hydrogen.

2. EXPERIMENTAL

The sliding tests as shown in Fig. 1 were made in chambers with gas purity control. Hardened bearing steel AISI 52100 and martensitic stainless steel 440C were used for the specimens. The diameter of the balls was 1/4 inch. Sliding tests were made with the same material for the disk and ball specimens in hydrogen and in vacuum, with a load of 20 N. The lubricant used was a silicone oil KF-95-10CS. The concentration of trace water in hydrogen was in the range of 3 to 5 ppm during the sliding tests.

Hydrogen content in the steels was determined by TDS. In order to take account of the changes in compositions of the steel surfaces, desorption spectrum of water was also analyzed. In TDS measurement, the specimens were gradually heated from 303 K to 1073 K at 10 K/min in vacuum chamber at a pressure level of 10^{-7} Pa.

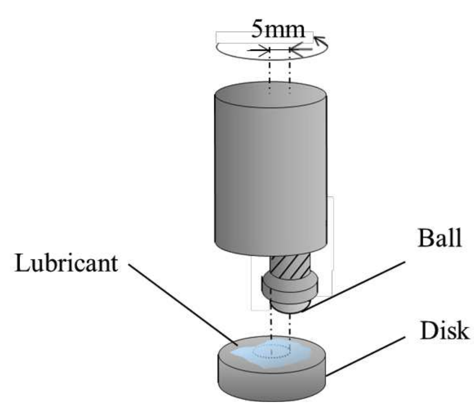

Figure 1 Sliding test.

3. RESULTS

Figure 2 shows the TDS spectrum for the 52100 disk specimens slid for 0.5 hours in hydrogen at 373K; the spectra for the specimen before the test and for the specimen exposed to hydrogen at 373K for 0.5 hours in hydrogen at 373K are also shown for comparison. The figure shows that there are two major desorption peaks at about 330°C and 500°C, and a small peak at 200°C indicating different sites in steel with different trap strength. Hydrogen permeated under sliding is trapped only in the sites with 330°C peak.

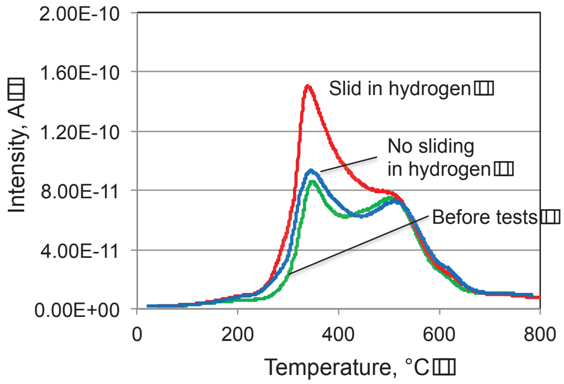

Figure 2 TDS spectra of the disk specimen before tests, after exposing to hydrogen at 373K for 0.5h, and after sliding in hydrogen at 373K for 0.5h.

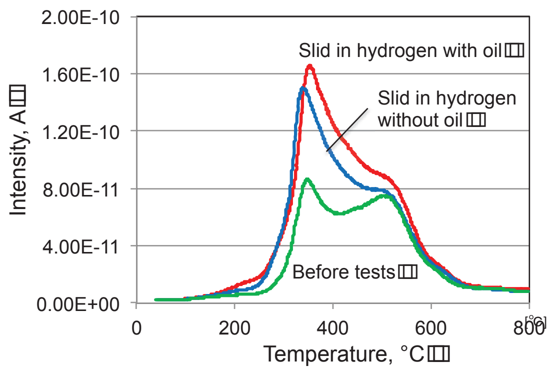

Figure 3 TDS spectra of the disk specimen before tests, and after sliding with and without oil in hydrogen at 373K for 0.5 hours.

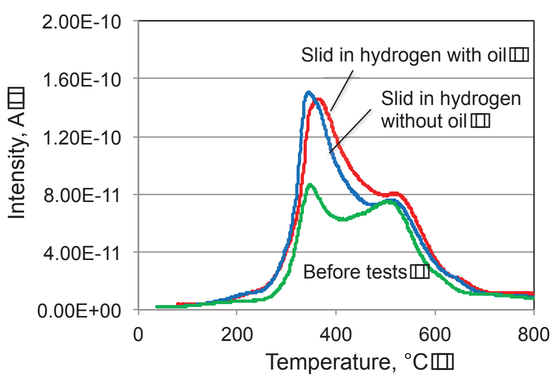

Figure 4 TDS spectra of the disk specimen before tests, and after sliding with and without oil in hydrogen at 373K for 2 hours.

Figure 3 shows the TDS spectrum for the 52100 disk specimens slid for 0.5 h in hydrogen at 373K with and without the oil. The amount of hydrogen permeated in the steel is slightly larger for the tests with the silicone oil. This is caused by the decomposition of the oil at the steel surface, although there may also be dissociation of hydrogen dissolved in the oil.

In further sliding, however, does not substantially increase the dissolved hydrogen as shown in Fig.4. The peak at 330°C rather shows slight decrease. This suggests the catalytic action for generation of hydrogen atoms has almost disappeared in both the unlubricated and lubricated sliding. Trace water and oxygen in hydrogen may have caused oxidation at the nascent surface. In lubricated sliding, asperity contact to produce nascent surfaces may have decreased due to the initial running-in wear.

The above results suggest that, under the present sliding conditions, the hydrogen uptake is significant in the early stage of sliding within 0.5 hours but is reduced in the subsequent sliding in hydrogen, both with and without the presence of oil. Further study is in progress to understand the formation and removal of oxides on steel in sliding contact.

Another series of tests is intended to see TDS spectra for the steels after hydrogen is removed by pre-heat treatment. The results indicate that TDS spectrum has peaks for hydrogen at different temperature, which not only suggests that the hydrogen originally contained in the steels is eliminated but also the trap sites for hydrogen has changed.

4. CONCLUDING REMARKS

The present experiments show that sliding contact in hydrogen and with the silicone oil causes hydrogen permeation into the steels. The rate of permeation appears to increase first and then decrease with time, suggesting the changes in the catalytic action of the nascent steel surface. Further study is necessary to understand the competing processes of wear and oxidation, and the changes in contact conditions under lubrication.

5. REFERENCES

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