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Hydrogen in automotive tribology

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1. Introduction

The connection between automotive science and hydrogen is closer than before as hydrogen use expands. There are concerns about how hydrogen affects the friction and wear properties of mechanical components in passenger cars. When thinking about hydrogen in the field of automotive science, there are two main aspects to consider. The first is the use of hydrogen as a fuel in fuel cell vehicles, hydrogen engines, etc. For hydrogen engines, there are several types of sliding and rolling bearings that run in hydrogen. The hydrogen infrastructure for hydrogen energy systems that refuel hydrogen vehicles also contains many mechanical elements that operate in hydrogen. Since hydrogen reacts with oxygen to produce water during the oxidation process, the effect of water on sliding friction in hydrogen must also be considered.

Second aspect is that "hydrogen is everywhere". Passenger car engine must be lubricated with oil. Hydrocarbon oils can release hydrogen when they decompose. It is believed that the rolling element bearings in automobile engine alternators had suffered from hydrogen embrittlement due to hydrogen decomposed by electrical charging on and around the fan belt. Water is also presence in engine that can also produce hydrogen.

As mentioned above, there are both sliding and rolling elements that operate in hydrogen environment and both exhibit unique physical and frictional properties in hydrogen. In this study, some basic tribotest results on both sliding friction tests and rolling contact fatigue test of rolling element bearing are introduced.

2. Experimental

In our laboratory, several sliding and rolling contact fatigue (RCF) tests have been conducted in hydrogen environment so far. Hydrogen gas from a cylinder, five nines pure, is used as the test gas. Hydrogen gas was basically overflowed from a test chamber to maintain its purity, because impurity in hydrogen gas, water and oxygen, must be avoided or controlled as much as possible. Prior to the test, sufficient gas exchange also must be performed not to remain the air at the test sample setting. If the test chamber has vacuum pump, sufficient evacuation has been made before the test. Concentration of water as the main impurity in hydrogen was monitored by moisture sensor during each test.

3. Sliding test in hydrogen

3.1 Sliding test of metals

Hydrogen system has many metal elements such as valves, seals and bearings. Due to concern about hydrogen embrittlement in hydrogen, stainless steels and nickel-based materials are commonly selected. However, coefficient of friction for these metals basically exhibit large coefficient of friction. In order to know the effects of metal species on friction and wear properties, a cross cylinders sliding test was conducted as shown in Fig. 1. Figure 1(a) was the sliding test results in Argon, and Fig. 1(b) was in hydrogen[1]. Words in legend, the left side word indicates moving part and right side indicates stationary part. As the figures shows, coefficient of friction was higher especially in Argon if moving side was Ni. In case of Ni/Cr, relatively low in friction and wear were shown in hydrogen. Cr in moving side led to low friction but large wear in hydrogen. As the results indicated that hydrogen gas affected in a different manner on friction and wear of metals compare to the inert gas.

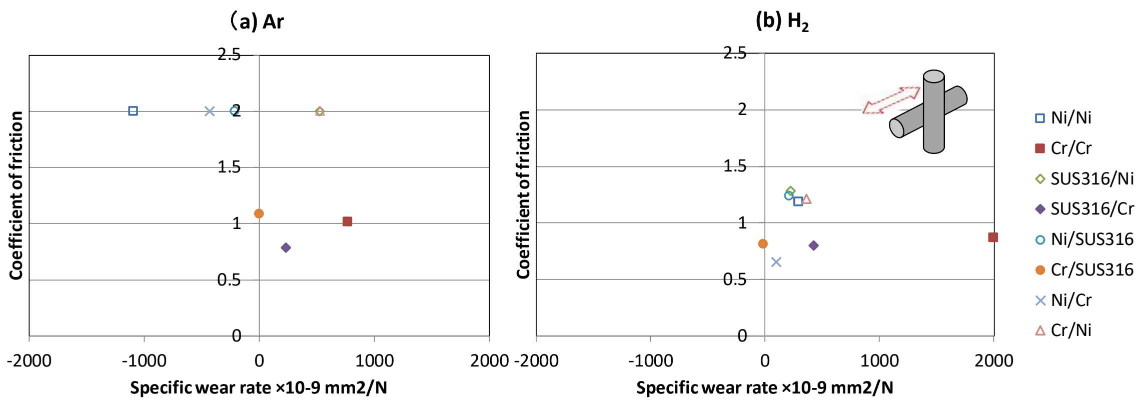

Fig. 1 Sliding test of metals in hydrogen, 1.96N, 2Hz, Stroke:1mm, 7200cycles

3.2 Sliding test of DLC coating

In order to improve wear property and reduce friction, coating is a very convenient way and DLC is one of the most promising solution. It is most important that hydrogen completely changes the friction and wear performance of materials as it prevents oxidation of the sliding surfaces. Situation is the same when we use DLC coating and metal used in valves and seals.

It is recognized that DLC exhibits very low friction and wear in hydrogen[2]. While achieving the low friction, thin and smooth transfer of carbon onto the counter surface formed, which strongly depended on environmental gas and materials. 52100 steel disks with DLC coating were used as disk specimens. Two types of DLC, a-C:H - hydrogenated DLC and ta-C-hydrogen free DLC, were used as coating disk. Pin specimens were DLC coated on the 52100 or uncoated pure metals, chromium, in this study.

Figure 2 showed the changes in coefficient of friction with sliding distance in one directional sliding test. Some metal species slid against DLC film particularly reduced friction and wear, though DLC/DLC contact didn't show particular low friction. Ambient air also didn't show significant low friction. As mentioned above, optimal matching of sliding pair and environmental gas made the DLC friction sufficiently low.

4. Rolling contact fatigue test in hydrogen

Rolling contact fatigue (RCF) life of rolling element bearing under hydrogen have been investigated. Previous results showed a shorter flaking life in hydrogen than Argon and Air[3]. Higher concentration of hydrogen in steel led to shorter flaking life which was demonstrated by the hydrogen concentration in the bearing steel measured by TDS, thermal desorption spectrometry after the RCF test. Therefore, permeated hydrogen in steel may result in the reduction of fatigue life, typically caused by hydrogen embrittlement.

However, ordinal hydrogen embrittlement and "white structure flaking" occurs in normal environment. Where does the hydrogen come from? We assume that hydrogen is produced by decomposition of lubricant, which may be atomic or ion hydrogen. They diffuse on surface and part of them meet each other and recombine to form gaseous hydrogen. The others may permeate and diffuse into solid material that involves with degradation of the material, which is known as hydrogen enhanced white structure flaking.

In this study, thrust roller bearing type RCF tester was used. Figure 3 shows the results for roller bearing life time in hydrogen compared to nitrogen that exhibits how the hydrogen affected the fatigue life of rolling element bearing. RCF life of roller bearing is significantly lower than that in nitrogen. That means hydrogen significantly reduces the RCF life.

Rolling element bearings are constantly lubricated, however, hydrogen gas dissolves easily in the lubricant and has a similar effect on the sliding elements. Dissolved hydrogen adsorbed to the rolling contact surface and avoided the oxidation of rolling contact surface. It also invades into solid which causes hydrogen embrittlement of rolling element bearing. Cross sectioning of rollers after the test revealed that a plenty of white etching constituents, sometimes along with crack, were observed on the inside of rolling contact of the rollers besides no change were observed on the outside of contact. This fact suggested that contact condition including local slip was very important addition to hydrogen presence on the contact surfaces.

5. Summary

Hydrogen effects on sliding and rolling contact have been discussed. Presence of hydrogen changes dramatically the contacting surface conditions as avoiding oxidation and/or other unique properties resulting in very unique friction and wear performance in automotive components. Most of them reduce lifetime of components compared to normal atmosphere, so it is important to know well about the hydrogen effects on operation of the components.

References

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3) Tanaka, H., Morofuji, T., Enami, K., Hashimoto, M. & Sugimura, J. Tribol. Online 8(1), 90–96 (2013).

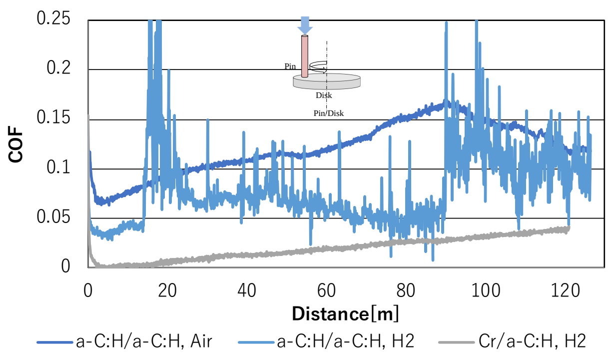

Fig. 2 Sliding test of DLC in hydrogen, 2N, 0.0628m/s

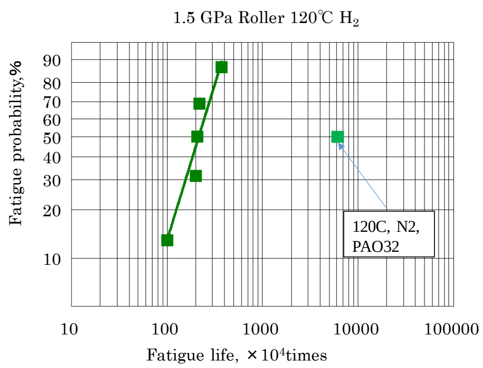

Fig. 3 Rolling contact fatigue test of roller bearing in hydrogen