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Fluorination and wear of aluminum alloy slid against PTFE

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Abstract – The phenomenon that the aluminum alloy is remarkably worn by sliding against the PTFE was investigated experimentally in comparison with other metals and other polymers. The large wear amount of aluminum alloy slid against PTFE was thought to be influenced not only by the hardness of the metal and the hardness of the counterpart resin material but also fluorination of the metal surface during friction with PTFE. As a result of XPS analysis of the sliding surface of aluminum alloy, it was considered that surface of aluminum alloy is considerably fluorinated by sliding against PTFE.

1. INTRODUCTION

Tribological properties of PTFE have been extensively studied from fundamental research to practical research since PTFE shows the lowest friction coefficient among various resin materials. It is known that PTFE forms a thin transferred film on the metal counterpart surface by friction, which greatly contributes to friction characteristics of PTFE. In addition, it was investigated that metal fluoride was formed on the metal counterpart surface by friction with PTFE, which is thought to affect the formation of transferred film. It was reported that the binding between the first PTFE transferred film and active metallic surface is chemical bonding and the bonds to the metal is via fluorine atoms [1], and it was reported that the greater the strength of adhesion the lower the rate of wear [2]. However, it is difficult to say that transferred film formation mechanism has been sufficiently understood. In order to understand the low friction mechanism of PTFE, it is necessary to clarify the fluorination reaction of metal and the formation mechanism of the transferred film.

In our previous study to investigate the abrasiveness of carbon fiber added to PTFE as a filler material to the counterpart metal surface, it was found that aluminum alloy, which is harder than PTFE, wears out considerably by the friction with unfilled PTFE [3]. It was also found by XPS analysis that the surface of the aluminum alloy is fluorinated. However, a causal relation between large wear amount of aluminum alloy and fluoridation of sliding surface of aluminum alloy is not clear. In this research, it was aimed to investigate the fundamental phenomena of wear of metal and fluorination of metal in friction between aluminum alloy and PTFE.

2. METHODOLOGY

2.1 Sample preparation

Fine PTFE molding powder, Fluon PTFE G163 (Asahi Glass Co., Ltd.), with a median particle size of 25 μm was used as raw material of PTFE specimen. PTFE powder put in a mold was compressed at 36.7 MPa while heating at 380 °C for 20 min. By this molding, a PTFE disk specimen with a diameter of 32 mm and a thickness of 2~3 mm can be obtained. As the main counterpart metal material, an aluminum alloy A5052 (Japanese Industrial Standards) was used for experiments. Other aluminum alloys (A1070 and A2017), pure copper (C1100) and stainless steel (SUS304) were also used for experiments in order to investigate the effect of metal hardness on the wear amount of metal specimen. In the case of a ring specimen, these metals are processed into a cylindrical shape. The outer diameter and inner diameter of the ring specimen are 16 mm and 12 mm respectively. The sliding surface of the ring specimen (the end face of the cylinder) was polished to provide a surface roughness of less than 0.02 μm (*Ra*). The specimen was cleaned ultrasonically with acetone before friction test.

2.2 Friction test

The friction test was carried out with a ring-on-disk system or a ball-on-disk system depending on the purpose, though the result of ball-on-disk friction test is omitted because of space limitations. The ring-on-disk friction test was carried out under a condition of an applied normal pressure of 1.11 MPa, a sliding speed of 0.51 m/s and a sliding distance of 1760 m at room temperature in a dry air (< 30% RH) atmosphere.

3. RESULTS AND DISCUSSION

Figure 1 shows wear amount of metal ring specimens slid against PTFE disk specimen (bar) and the Vickers hardness of the ring specimens (circle mark). For the aluminum alloy, the wear amount of metal counterpart decreases with the increase of the hardness of sliding surface. Here, the hardness of sliding surface of pure copper specimen was comparable with that of aluminum alloys, however, there was no wear of copper specimen. Therefore, it is difficult to explain the wear amount of the metal specimen slid against PTFE only with the hardness of the metal.

In order to consider the effect of the hardness of polymer material on the wear amount of aluminum alloy counterpart, the wear amount of aluminum alloy slide against PTFE, UHMWPE, and POM were compared. Figure 2 shows the wear amount of aluminum (A5052) ring specimen slid against three kinds of polymer disk specimens and the Durometer hardness (Type D) of polymer specimens. Here, UHMWPE was chosen because its molecular structure is similar to that of PTFE. Since the durometer hardness of POM is higher than that of PTFE, it can be explained that the wear amount of aluminum alloy rubbed with POM is larger than that rubbed with PTFE. However, despite the durometer hardness of UHMWPE being higher than that of PTFE, the wear amount of aluminum alloy rubbed with UHMWPE is quite small. So, from these results shown in Figure 1 and Figure 2, we can consider that some other factor may affect the wear of aluminum alloy, not only the hardness of metal or the hardness of polymer material.

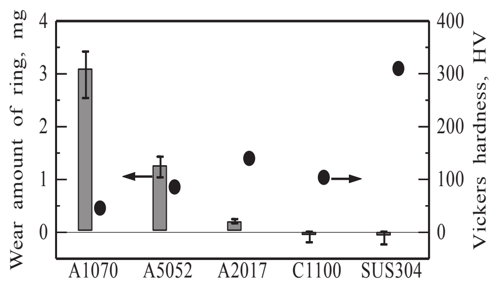

Figure 1 Wear amount of the ring specimens after sliding against PTFE and Vickers hardness of the ring specimens before friction test.

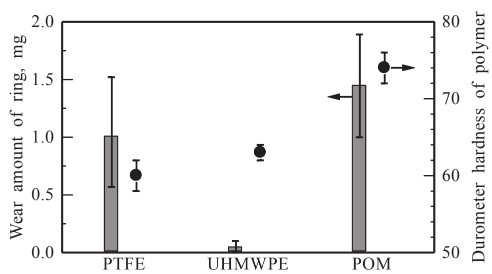

Figure 2 Wear amount of A5052 ring specimen after sliding against polymer specimens and durometer hardness of polymer specimens.

Figure 3 show the XPS spectra obtained from the sliding surface of A5052 ring specimen slid against PTFE. Fig. 3(a) & 3(c) show the C1s (carbon) peak and Fig. 3(b) & 3(d) show the F1s (fluorine) peak. Fig. 3(a) & 3(b) were obtained from the sliding surface as it was subjected to friction test, and Fig. 3(c) and 3(d) were obtained from the sliding surface after argon ion sputtering treatment. Before sputtering treatment, two peaks of C1s was obtained as shown in Fig. 3(a). The peak at around 292 eV arise from carbon of PTFE and the peak at around 285 eV arise from hydrocarbon such as contamination. This means that the transferred film of PTFE was generated on the surface of aluminum alloy. The peak of F1s consists of multiple peaks as shown in Fig. 3(b). One of them at around 689 eV arise from fluorine of PTFE and the others could be from aluminum fluoride (AlF_3) or aluminum oxyfluoride (AlO_xF_y). After sputtering treatment, C1s peak from PTFE almost disappeared as shown in Figure 3(c), on the other hand, F1s peak remained as shown in Figure 3(d). This result means that metal fluoride is detected even after a sufficient amount of sputtering treatment to remove the transferred film of PTFE, therefore, it is considered that the surface of aluminum alloy is considerably fluorinated by sliding against PTFE.

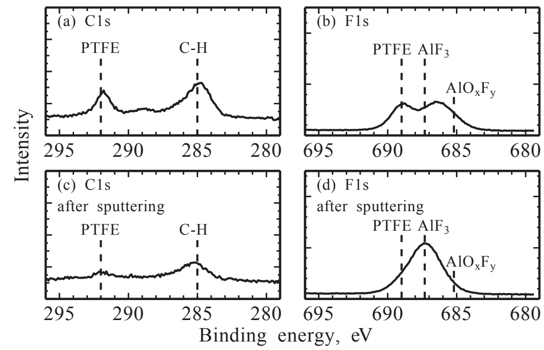

Figure 3 XPS spectra obtained from A5052 ring specimen after sliding test for C1s peak (a,c) and F1s peak (b,d). Spectra were obtained before sputtering (a,b) and after 1 min sputtering (c,d).

It is well known that fluorination of metal counterface is the result of tribochemical reaction between PTFE and metal surface. And this reaction could make strong adhesion of PTFE transferred film to the metal counterface. However, it causes abrasion of the metal surface if the aluminum fluoride is brittle and easily removed from the surface by rubbing. Therefore, the non-negligible wear amount of aluminum alloy slid against unfilled PTFE could be attributed to not only the softness of aluminum alloy in comparison with other metal but also the mechanical properties of metal fluoride.

4. CONCLUSION

In the friction between the metal and PTFE, metal fluoride is formed on the metal surface. The wear amount of the aluminum alloy slid against PTFE was remarkably large. This is considered to be caused by the aluminum fluoride which is formed in addition to the fact that the aluminum alloy is a relatively soft metal.

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