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Effect of surface electric potential on friction coefficient of ionic liquids

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ABSTRACT – The controlling of lubricating performance of lubricants is very attractive method. This study investigated the effect of surface electric potential on lubricating performance of ionic liquids against tetrahedral amorphous carbon film in macro-scale friction. The friction coefficient of 1-butyl-3-methylimidazolium iodide was unchanged by the surface electric potential because this ionic liquids was difficult to move in the solution. On the other hand, the friction coefficient lubricated with 1-butyl-3-methylimidazolium tris(pentafluoroethyl)trifluorophosphate, and 1-butyl-3-methylimidazolium hexafluorophosphate were changed when the surface electric potential was +2.0 V. It was considered that adsorption structure of ionic liquids affected the friction coefficient.

1. INTRODUCTION

Ionic liquids are organic salts consisting of cations and anions that can form liquids state at room temperature. They have various attractive physical properties, such as low vapour pressure, high thermal stability, high ionic conductivity, non-combustibility, and wide electric potential window [1]. H. Kondo et al. reported the lubricating performance of ionic liquids for the first time in 1989 [2]. After that, about the kind of ionic liquids as lubricants, fluorine, sulphate, phosphate, and cyano based ionic liquids were mainly investigated [3]. The state of molecular derived from ionic liquids on the solid surface are very important role on lubricating performance. Fluorine, sulphate, and phosphate based ionic liquids often form the tribo-reaction film with metal surfaces [4]. On the other hand, cyano-based ionic liquids often form the adsorption film on metal surfaces [5]. Recently, the controlling the kind of adsorption ions on the solid surface was carried out. Atkin et al. showed the lubricating performances of ionic liquid can be controlled by the solid surface electric potential [6]. However, this experiment was carried out Atomic Force Microscope (AFM). In addition, the gold substrate was used as sliding material. Thus, the effect of surface electric potential on the lubricating performances of ionic liquids in macro-scale friction and against industrial material are unclear.

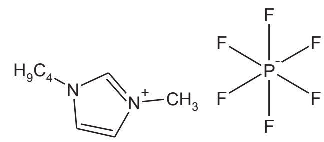
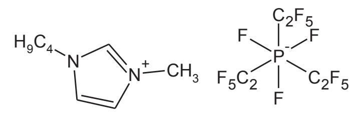
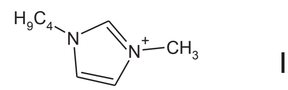
This study investigated the effect of surface electric potential on lubricating performance of ionic liquids against industrial material in macro-scale friction.

2. EXPERIMENTAL DETAILS

2.1 Lubricants

In this study, 1-butyl-3-methylimidazolium tris(pentafluoroethyl)trifluorophosphate ([BMIM][FAP]), 1-butyl-3-methylimidazolium hexafluorophosphate ([BMIM][PF_6]), and 1-butyl-3-methylimidazolium iodide ([BMIM][I]) were used as lubricants. They were purchased form Merck. Table 1 lists the chemical structures of the tested ionic liquids.

Table 1 Chemical structures of ionic liquids.

Name	Chemical structure
[BMIM][FAP]	
[BMIM][PF_6]	
[BMIM][I]	

2.2 Sliding tests

The lubricating performance of each ionic liquid was evaluated using an in-house instrument palate-on-plate friction tester as shown in Fig. 1 (ϕ 24 mm × t 7.9 mm plate made of bearing steel (AISI 52100)). To prevent electric corrosion and energization between both specimens, the both specimens were coated with tetrahedral amorphous carbon film by arc ion plating method and jig was made of Teflon. The surface roughness of specimens were 0.01 µm. The upper specimen connected to ground. The bottom specimen connected to electrode. A platinum worked as counter electrode and be inserted in the ionic liquids.

The operating parameters were a load of 10 N, rotation speed of 0.75 rpm, break-in time of 60 min, surface electric potential of 2.0 V and -2.0V, application time of 10 min.

3. RESULTS

Figure 2 shows the friction behaviour of each ionic liquid by surface electric potential. All ionic liquids showed difference friction coefficient when the 0 V (50-60 min). [BMIM][I] exhibited the lowest friction coefficient of 0.05. Other ionic liquids exhibited the high friction coefficient of more than 0.06. When the bottom specimens was -2.0 V (60-70 min), the friction coefficient was almost unchanged. On the other hand, in the case of [BMIM][FAP] and [BMIM][PF_6] the friction coefficient was increased when the bottom specimens were 2.0 V (70-80 min). [BMIM][I] almost unchanged about friction coefficient.

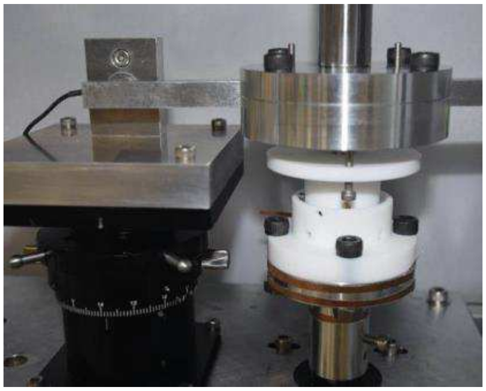


Figure 1 Picture of testing apparatus.

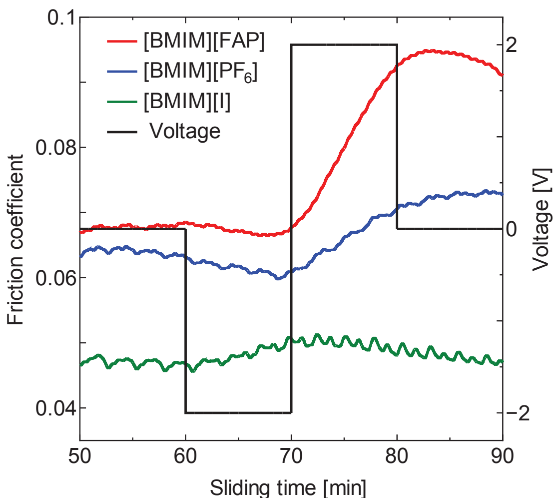


Figure 2 Friction behaviour of each ionic liquid.

4. DISCUSSIONS

4.1 Responsiveness against surface electric potential

The friction coefficient of only [BMIM][I] was almost unchanged when the surface electric potential was applied. It is considered that ion conductivity affected friction behaviour. That of [BMIM][FAP], [BMIM][PF_6], and [BMIM][I] are 2.3, 1.34, and 0.5 mS/cm, respectively. It was believed that [BMIM][I] was difficult to move in the solution.

4.2 The state of ionic liquids against surface electric potential

It is well known that ionic liquids form electrical double layer on electrode [6, 7]. In addition, ionic liquids forms film stack by the electrical force between the cations and anions [7]. Figure 3 shows the model diagram of ionic liquids against surface electric potential. First layer have strongly interaction with the surface electric potential. The second and succeeding layers have interaction between the cations and anions. Thus, the first layer especially affected the difference of friction coefficient lubricated with [BMIM][FAP], and [BMIM][PF_6] in the case of +2.0V. When the surface electric potential was -2.0 V, the first layer was same ion. Thus, the second and succeeding layers affected the difference of friction coefficient lubricated with [BMIM][FAP], and [BMIM][PF_6] in the case of -2.0V.

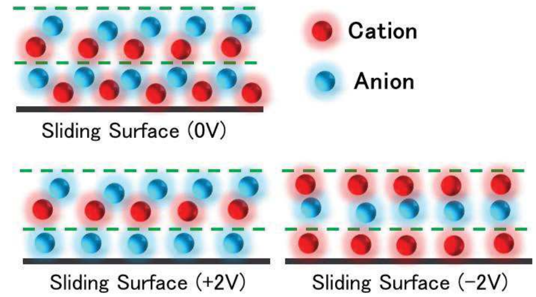


Figure 3 the model diagram of ionic liquids against surface electric potential.

5. SUMMARY

This study investigated the effect of surface electric potential on lubricating performance of ionic liquids. The friction coefficient lubricated with [BMIM][FAP] and [BMIM][I] was changed in the case of -2.0V. However, the friction coefficient lubricated with [BMIM][I] almost unchanged because this is difficult to move in the solution. It is considered that the friction coefficients lubricated with ionic liquids were affected by adsorption structure of ionic liquids.

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