NOVEL IONIC LIQUID LUBRICANTS FOR AEROSPACE AND MEMS

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INTRODUCTION

Room temperature ionic liquids (RTILs) are molten salts with melting points at or below room temperature. RTILs have recently been recognized as novel lubricants. Only a few have previously been evaluated.

RTILs have unique properties ideal for lubricants. Their negligible vapor pressure allows interoperability in vacuum and air. They have very low friction on both metallic and nonmetallic substrates, and high electrical conductivity advantageous for electrical contacts. Until now, RTILs did not have better wear-reduction properties than conventional formulated lubricants.

Careful selection of RTILs is necessary; not all are suitable for tribological use. Some are moisture-sensitive, corrosive toward metals and/or have poor surface wettability.

In this work, new ionic liquid lubricants were successfully predicted and demonstrated. Ionic structural features that determine surface interactions and lubricating behavior were evaluated with fundamental surface science, tribological testing and ionic shape analysis/modeling, and were shown to correlate with the performance of RTILs as lubricants in both standard and microscale (for MEMS) tribological evaluations.

Ionic liquid lubricants with low friction, excellent wear prevention properties (equivalent to formulated engine oil), and excellent lubricity on noble metals and silicon, as well as on ferrous and non-ferrous metals, are described.

IONIC LIQUID SELECTION

Ionic Liquid Compositions. In RTILs, one or both of the ions are organic species. Compositions with relatively large and/or asymmetric ions reduce their packing density, accounting for their liquid state. Typical cations include imidazolium, pyridinium, ammonium, phosphonium and sulfonium, illustrated below.

![Ionic Liquid Compositions](image)

Typical anions include tetrafluoroborate, BF$_4^-$, hexafluoro-phosphate, PF$_6^-$, (CF$_3$SO$_2$)$_2$N = “triflamide”, Tf$_2$N, and toluene-4-sulfonate = “tosylate”, Ts. These are by no means exhaustive.

Selection. In the previous tribological literature, only RTILs with dialkyl imidazolium cations and BF$_4^-$ and PF$_6^-$ anions have been reported [1-4]. In addition, we selected many new non-imidazolium and non-fluoroanion ionic liquids for study, based on prediction of the effects that cation and anion chemical composition and shape would have on expected lubrication behavior. Imidazolium cations are relatively flat rings. Other ion shapes and sizes included both larger and smaller ions with both rigid and flexible components.

From among 300 ILs, we selected 17, in a systematic series with common anions and common cations. Most were liquids with typical lubricant viscosities and viscosity indices (VI). Some low-melting solids completed several structural series. RTILs were custom-synthesized if not available.

Surface wettability, material interactions, thermal stability, macro- and microtribology for MEMS were evaluated.

SURFACE WETTING AND MATERIAL INTERACTIONS

The formation and retention of a lubricating film at surfaces in contact implies wetting and spreading on the mating surfaces without deleterious etching or corrosion. RTILs were screened for wetting and compatibility with 11 materials.

Small (ca 2mm) drops were applied to clean flat surfaces and photographed at several hour intervals. Figure 1 shows wetting and non-wetting RTILs on 440C steel, gold, and glass.
Figure 1. RTILs on (a) 440C steel, (b) gold, (c) non-wetting glass and (d) wetting glass.

Figure 2. Relative wettability of 12 ionic liquids on 11 surfaces. Data ranked and cells colored from 0=gray =nonwetting to 4=red =complete spreading.

**Cation Effect.** Surface wetting characteristics of ionic liquids were most strongly dependent on the nature of the cation. Non-imidazolium RTILs, shown in the lower section of Figure 2, wet surfaces better than comparable imidazolium salts on all surfaces—metals, noble metal, ceramics, and silicon. Among imidazolium salts, there is an anion effect, in which oxyanions significantly increase wettability.  

**Substrate Effect.** In general, both imidazolium and non-imidazolium ionic liquids wet noble metal and nonmetal surfaces better than conventional metal surfaces. Wetting and spreading were better on gold, silicon nitride, glass and silicon than on stainless steels, Inconel, aluminum or titanium.

**TRIBOLOGY STUDIES**

**Tribology Methods.** Four-ball wear/friction tests were conducted according to ASTM D-4172, in air: 52100 steel balls 40 kg load (3.4 GPa pressure), 75°C, and 1200 rpm (0.46 m/s).

Microtribometer pin-on-disk friction was obtained with lubricated gold pins on a polysilicon counterface, in both air and argon at 0.15 GPa pressure, 25°C, oscillating at 1.5 mm/s. Repeatability of friction in all tests was ±0.01.

**Cation Effect.** Wear prevention by ionic liquids was found to be strongly dependent on the cation. RTILs with non-imidazolium cations prevented wear of steel much better than any imidazolium salt. The negative anion had been predicted to more strongly influence interfacial behavior. Wear of 17 RTILs is shown by cation type in Figure 3, where the consistent cation effect on lubrication with ionic liquids is easily observed.

**Wear Prevention Without Additives.** Several new RTILs, without antiwear additives, gave extremely low wear of steel, comparable to fully-formulated engine oils. The best imidazolium salts had wear an order of magnitude greater than the most effective new RTILs.

Anions with surface interactions analogous to those of conventional lubricants were among those with the lowest wear. Thus, the proposed anion effects may well occur, but are secondary to the cation effect.

**Consistently Low Friction.** All ionic liquids had friction coefficients lower than all conventional lubricants not containing friction modifier additives. Friction for the 17 RTILs in Figure 3 are shown in Figure 4, with PFPE and engine oil again as references. Friction for RTILs did not show a trend, but all RTILs had extremely low friction without any additives.

**Friction Independent of Surfaces or Atmosphere.** Friction coefficients of all ionic liquids were remarkably similar, and independent of the materials lubricated or the environment. All friction coefficients were in the narrow range of 0.06 to 0.08, lubricating steel-on-steel or gold-on-silicon contacts, in air or in inert atmosphere, 75°C or 25°C, at high or low load. RTIL friction appears independent of contact material.

**ACKNOWLEDGMENTS**

Support by U.S. Air Force Office of Scientific Research, Contract FA9550-04-C-0135 is gratefully acknowledged.

**REFERENCES**