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Effect of different lubricants on microstructural and tribological properties of TC21 titanium alloy against Si_3N_4 under fretting–reciprocating sliding

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ABSTRACT

The tribological properties of a Si_3N_4 ball sliding against a TC21 disc lubricated by pentaerythritol ester (5750), bis (2-ethylhexyl) sebacate (1088), 1-butyl-3-methylimidazolium tetrafluoroborate (L-B104) and an as-synthesized ionic liquid L-$C_8F_{17}SO_3P_{4444}$(L-4P) have been studied by an Optimol SRV-V oscillating reciprocating friction and wear with load, temperature and frequency. Scanning electron microscopy and X-ray photoelectron spectroscopy results showed that L-4P has an excellent extreme pressure wear resistant effect (750N) and the lowest friction coefficient (<0.08), in addition to possess excellent tribological behavior due to the formation of chemical reaction (SnF_2 and a friction oxidation product lubrication film) and deposition films on the rubbing surface. The wear mechanisms were mainly adhesive wear, abrasive wear and microcosmic fatigue wear, with less cracks on the worn surface. Under the 5750, 1088 and L-B104 lubrications conditions, the friction coefficients were markedly increased with the load increasing and the values were larger, friction surface was a clear plowing effect. The wear mechanisms were mainly surface plowing and abrasive wear. In this investigation, the results demonstrated that L-4P could react with the TC21 titanium alloy to produce lubrication film to improve the tribological properties.

With the rapid development of information technology, it has become the trend of the future that adopts the shorter wave length electron to replace laser processing and checking. If the wafer fixture is equipped with a magnetic bearing and rotating around the electron beam gun, then the area around the bearing will generate a magnetic field, which undoubtedly affects the accuracy of electron beam processing and checking. Therefore, in this case the conductivity of the bearing materials should be extremely low [1,2]. At present, it mainly adopts anti-magnetic stainless steel and beryllium bronze alloy bearings because they have good conductivity and anti-magnetic. However, due to the strong toxicity of beryllium bronze alloy, it should be used as little as possible. Anti-magnetic stainless steel magnetic permeability is from 1.001 to 1.01, belonging to micro magnetic material, but as the electron beam device bearing material is still not appropriate, because the austenite stainless steel occurs martensite phase transformation when is plastic deformation and leads to magnetic, affecting the precision of the electron beam [2]. In contrast, titanium alloy has good conductivity and anti-magnetic, compared with the magnetic stainless steel or beryllium bronze alloy, the better resistance to corrosion and the weight is reduced nearly a third, can be used as the best choice of the electron beam device bearing material [3]. Jackman, Joseph, Hannah and Wayne invented a new type titanium alloy bearing steel and American Patent Number is 4279650 [4]. Japanese company NSK ltd, Japanese famous factory, developed non-magnetic corrosion resistant titanium alloy bearing, and its hardness is HV500 and which exceeds beryllium bronze and non-magnetic stainless steel, the load increases from 950N to 2600N [5–7]. The inner and outer ring of the deep groove ball bearing are made of titanium alloy, and the ball is used to adopt silicon nitride ceramics(Si_3N_4), hold on USES the fluorine resin, after rotating 1×107 it has good performance without wear problems. Swedish company SKF ltd., Swedish, designed a new type of titanium bearing for airbus A380 in 2005, compared to traditional bronze and steel bearing, it reduces as much as 40% weight, can be reduced each landing gear at least 100 kg weight [8]. Therefore, it is becoming very important for high performance titanium alloy development and lubrication of silicon nitride ceramics.

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However, although titanium alloy long ago crossed the barrier between laboratory curiosity and high-value consumer product, the poor tribological behavior (in terms of high and unstable friction, severe adhesive wear, low resistance to abrasion, susceptibility to fretting wear and a strong tendency to seize) has restricted, to date, the very large-scale uptake of titanium alloys, especially under dynamically loaded conditions [9]. For example, severe adhesive wear may occur when a titanium surface slides against any engineering surface, whether it is metallic, ceramic or polymeric, under a medium-to-high load, thus forming ‘a handful of debris’ [10]. More recently, Li et al. [11] investigated the effect of counterface materials on the sliding wear of g-based titanium aluminides under 10 N loads without lubrication. These results indicate that sliding contact of TiAl intermetallics against ceramics of Al_2O_3 or Si_3N_4 may not be desirable designs, since these tribopairs can result in a very high overall wear loss. Severe adhesive wear of titanium occurs not only under sliding conditions but also under rolling–sliding conditions with oil lubrication [12].

With the high speed developing of lubrication technology, the new type lubricant appears constantly, especially the ionic liquid lubricant and a new type of lipid lubricant can reduce the friction coefficient, wear rate and increase the use temperature of most friction pairs. For example, Ye Yang, Chenhui Zhang and Yan Wang investigated friction and wear performance of titanium alloy (Ti–6Al–4V) against tungsten carbide(WC) lubricated with phosphate ester, and the adsorption of phosphate to titanium through P–O–Ti covalent bond formed a steady film preventing direct contact of the ball with the disc, thus a relatively low friction coefficient and wear rate [13]. Ye Yang [14] investigated the tribological behaviors of titanium alloy–tungsten carbide friction pair lubricated by oil or water based lubricants. The results show that self-emulsifying ester, either oil phase or aqueous solution, has good friction reduction performance on titanium alloys while the commonly used paraffin and PAO fail to lubricate this system. Qu [15] studied the lubricity of an alkyl quaternary ammonium tetrafluoroborate ILs on a steel/steel friction pair, coming to the conclusion that quaternary ammonium ILs have better tribological properties when used as both lubricants and lubricating oil additives. Ionic liquids (ILs) have been studied as lubricants of titanium against steel both at room and high temperature by Jiménez's group [16–18]。 They found some reactive ILs could reduce friction coefficient and wear rate at 300 °C and the alkyl chain length influenced ILs' lubricating properties. Wang et al. studied the lubricity of lithium-based ILs on Ti_3SiC_2/Si_3N_4 contacts and discovered that they have better tribological properties when used at room and high temperatures [19]. Fan et al. studied the lubricity of perfluorooctane sulfonate ILs on steel/steel, steel/tin-bronze and steel/aluminum contacts, finding that they have better tribological properties when used at room and high temperatures [20].

In case of Ti–64Al–4V, the commonly used titanium alloys, due to low hardness, it cannot be used for the rolling bearing with high contact pressure [2]. TC21 titanium alloy is a new type of high performance titanium alloy with high hardness (490HV), corrosion resistance and bearing capacity, it has a wide application prospect. It's an ideal material for non-magnetic and corroision-resistant titanium alloy bearings, but it is easy to be stick and poor wear resistance [21], which is rarely used as friction parts. The problem of friction, abrasion and lubrication of TC21 titanium alloys is an item of work with extraordinary significance.

Up to now, few researches have been done to investigate the effective commercial base ester oils and ILs with titanium alloys considering the lubricating and anti-adhesion properties. This paper intends to study the friction and wear behavior of TC21 titanium alloy against silicon nitride ceramic ball as friction pairs, applying two commonly used lubricants 5750 and 1088 as well as two ionic liquid lubricants. This paper aims to provide an effective lubrication for $TC21/Si_3N_4$ compared with $TC4/Si_3N_4$. The friction and wear mechanisms involved are discussed to study the tribological behavior sliding against Si_3N_4 ceramics. To advance the scientific understanding, the tribological properties of the counterparts in lubricated conditions (base ester oils and ILs) are also reported.

1. Experiment

1.1. Materials

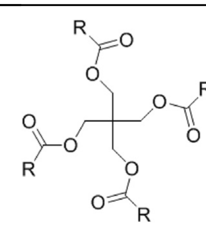
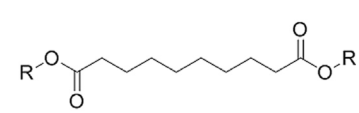
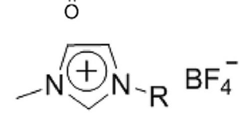
The Ti–6Al–2Zr–2Sn–2Mo-1.5Cr–2Nb(TC21)and Ti–64Al–4V (TC4) alloy in sheet form with a thickness of 2 mm was supplied by the Institute of Northeast institute for non-ferrous metal research in China.

The chemical structures of the ILs and base oil used in this study are given in Table 1. The conventional IL, L-B104 was provided by the Lanzhou Institute of Chemical Physics. 1088 (Amethyst Chemicals, 97%) and 5750 (NYCO Company) were used. The other chemicals are commercially available: tetrabutylphosphonium bromide ($P_{4444}Br$, 98%, J&K), and potassium heptadedecafluoro-1-octanesulfonate (98%, Energy Chemical). L-4P was synthesized according to a literature procedure [22,23].

1.2. Thermal analysis

The thermal stabilities of the as-synthesized IL and the reference samples were determined according to the following method. First, increasing temperature thermogravimetric (TG) analysis was carried out on a Netzsch STA 449 F3 synchronous thermal analyzer system under nitrogen atmosphere using an alumina crucible. During the increasing temperature TG analysis, the temperature was monitored to increase from RT to 600 °C at a heating rate of 10 °C/min. The percentage of weight loss with a rise in temperature

Table 1
Chemical structures, names and codes of the used samples.

No	Samples and name	Structure
1	5750 R = C_7 C_8 alkyl	
2	1088 R-Isooctyl	
3	L-B104	
4	L-4P L-$C_8F_{17}SO_3P_{4444}$