Tribological properties of \(\gamma\)-TiAl alloy sliding with various counterbodies

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Tribological behavior of gamma titanium aluminide (\(\gamma\)-TiAl) alloy is investigated while sliding against 100Cr6 steel, SiC and Al\(_2\)O\(_3\) as counterbodies for friction pairs. Depending upon the type of counterbody, two different types of interaction and friction mechanism is governed that is harder \(\gamma\)-TiAl alloy and softer ball (\(\gamma\)-TiAl/steel sliding combination). However, in SiC and Al\(_2\)O\(_3\) balls, the harder/harder sliding combination acts to describe the wear mechanism. The deformation of the wear track is governed by these sliding combinations.

Keyword: \(\gamma\)-TiAl alloy, Friction, Counterbody, Sliding combination

Alloy of TiAl intermetallics have possess a remarkable combination of light-weight, high strength-to-density ratio, high strength at elevated temperature and good corrosion, oxidation and wear resistance\textsuperscript{1-4}. As a potential new structural material used as aerospace and automotive parts for turbine blades, divergent flap, turbocharger or nozzles, and exhaust valves, etc, these applications relate to friction and wear. However, several investigations show that titanium aluminides have poor wear resistance which would limit their applications\textsuperscript{5-7}. However, tribological properties of \(\gamma\)-TiAl alloy under high temperature and liquid paraffine lubrication performed well\textsuperscript{8,9}. Further, in order to enhance the wear resistance of TiAl based intermetallics, surface treatment technologies such as plasma carburization\textsuperscript{10}, laser treatment\textsuperscript{11}, gas nitridation\textsuperscript{12}, microarc oxidation\textsuperscript{13}, and thermal oxidation treatment\textsuperscript{14} have been utilized. However, there are less studies reported on the dry sliding tribological mechanism of the TiAl based composites. Although, it is known that the incorporation of ceramic have a good effect on enhancing the wear resistance and mechanical properties of intermetallics and alloys\textsuperscript{15}. In this accordance, the wear mechanism of \(\gamma\)-TiAl alloy sliding with various counterbodies is so far, not well understood. Therefore, in this perspective, wear behavior of \(\gamma\)-TiAl alloy sliding with Al\(_2\)O\(_3\), SiC and Cr6 steel ball is carried out in the present study. Further, the deformation of wear track and friction behavior is correlated.

**Experimental Procedure**

The \(\gamma\)-TiAl alloy used in this study has a nominal chemical composition of (at %) Ti-48Al-2Nb-2Cr. Rod samples of about 15 mm in diameter and 200 mm in length were sinter-melted by additive electron beam melting (AEBM) process. The samples cut from the rods are mechanically grinded with SiC paper and finally polished with \(\frac{1}{4}\) \(\mu\)m diamond paste. The surface morphology and microstructure of the coatings were analyzed using a scanning electron microscope. X-ray diffraction was used to study the structure and phase. Linear reciprocating mode of ball on the disk microtribometer (CSM Instruments, Switzerland) was used to carry out the friction measurements. In these measurements, the normal load and sliding speed were constant 5 N and 4 cm/s, respectively. Three different kinds of balls counterbodies such as 100Cr6 steel, SiC and Al\(_2\)O\(_3\) were used for sliding against \(\gamma\)-TiAl alloy. The diameter of the ball was 6 mm. Surface roughnesses of the balls were 0.04, 0.02, and 0.03 \(\mu\)m for 100Cr6 steel, SiC and Al\(_2\)O\(_3\), respectively. Tribological experiments were conducted in ambient atmospheric condition at room temperature where the relative humidity was 75%. In-situ wear track depth was measured by linear variable differential transformer (LVDT) sensor coupled to the micro-tribometer.

**Results and Discussion**

The microstructure of the \(\gamma\)-TiAl alloy was observed by optical microscope (Fig. 1). It shows duplex type morphology consists of equiaxed \(\gamma\) and lamellar colonies of \(\gamma\) and \(\alpha\) phases. In the XRD, the mixed
phase of $\gamma$ and $\alpha$ phase of TiAl with different orientation are shown in Fig. 2. The cubic Al$_3$Ti phase is predominantly mixed with AlTi phase.

Friction coefficient of $\gamma$-TiAl alloy was measured against three different kinds of balls such as Al$_2$O$_3$, SiC and Cr6 steel as shown in Fig. 3. The magnitude of this value is high when it slides against Al$_2$O$_3$ and SiC balls as shown in Fig. 3(a,c). However, against steel ball it shows less value of friction coefficient [Fig. 3(b)]. As well penetration depth is more or less similar in all the cases as shown in Fig. 4. However, deformation behavior of wear track is different while using these balls. It is shown in Fig. 5. The wear track width is large when Al$_2$O$_3$ and SiC balls slides against $\gamma$-TiAl alloy as shown in Fig. 5(a,c). However, against steel ball it shows narrow wear track [Fig. 5(b)].

In this accordance, the relationship of friction coefficient and deformation behavior of wear track is similar. The Al$_2$O$_3$ and SiC balls are harder which is more capable to deform the $\gamma$-TiAl alloy. The hardness and elastic modulus values are shown in Table 1. In this case, both the sliding interfaces (coating and ball) are harder which acts to deform more. This is the basic reason that harder balls such as Al$_2$O$_3$ and SiC shows high friction coefficient. When harder interfaces slides, the wear mechanism is governed by abrasive wear\textsuperscript{6,15}. However, steel ball is
softer compared to γ-TiAl alloy. In this condition, deformation of γ-TiAl alloy is less compared to steel ball. This explains less deformed and narrow wear track when steel ball slides against γ-TiAl alloy. In all the three cases, the wear rate \( k \) is calculated considering wear volume \( V \), normal force \( F \) and sliding distance \( S \):

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k = \frac{V}{F \times S}
\]

Wear volume was obtained by measuring the wear track width, depth and length using Dektek contact profiler. The wear volume was lowest 2.8 mm\(^3\) in steel/γ-TiAl sliding combination. However, this was increased to 3.2 and 4.8 in Al\(_2\)O\(_3\)/γ-TiAl and SiC/γ-TiAl sliding system, respectively. Wear rate is lowest 2.8×10\(^{-7}\) mm\(^3\)/Nm while γ-TiAl alloy slides against steel ball. However, this value increases to 1.8×10\(^{-6}\) mm\(^3\)/Nm and 4.7×10\(^{-6}\) mm\(^3\)/Nm while sliding against Al\(_2\)O\(_3\) and SiC balls, respectively. The trend of wear rate follows the trend of friction coefficient. The wear rate is less where friction coefficient is lower.

The origin of friction and wear mechanism observes in macroscopic level is related to microscopic one\(^\text{16}\). The micromechanical tribological mechanisms describe the stress and strain formation at an asperity-to-asperity level, the crack generation and propagation, material liberation and particle formation. Shear and fracture are two basic mechanisms for the first nucleation of a crack and for its propagation, until it results in material liberation and the formation of a wear scar and a wear particle\(^\text{16}\). An important parameter is hardness of the sliding interfaces and its relationship. It is common to consider hard and soft materials. The advantages of soft materials to reduce friction are well known. Soft materials have the function of reducing sliding originated surface tensile stresses, which contribute to undesirable subsurface cracking and subsequently to severe wear. A hard material on a softer ball can decrease friction and wear by preventing ploughing both on a macro scale and a micro scale. These materials typically exhibit residual compressive stresses which can prevent the likelihood of tensile forces occurring.

**Conclusions**

Tribological behavior of γ-TiAl alloy is investigated while sliding against 100Cr6 steel, SiC and Al\(_2\)O\(_3\) as counterbodies for friction pairs. The friction coefficient and wear rate was high when γ-TiAl alloy slides with Al\(_2\)O\(_3\) and SiC ball. However, these values were less while sliding against steel ball. The wear mechanism is explained by the sliding combination of harder/harder ball/γ-TiAl in case of SiC/TiAl and Al\(_2\)O\(_3\)/TiAl alloy. However, softer/harder sliding combination acts in steel/γ-TiAl alloy. Penetration depth during friction measurement shows more or less similar value. This
means that magnitude of composite wear is similar in all the three sliding combination. However, deformation of wear track follows the trend of friction coefficient. The wear track is wider in the sliding combination of SiC/γ-TiAl and Al₂O₃/TiAl alloy. However, in steel/TiAl alloy sliding combination the wear track was narrow.

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