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Research Paper

ANALYSIS OF FRICTION AND WEAR OF TITANIUM ALLOYS

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Due to the lower-cost processing of titanium, its application in the engines as light weight material has renewed its interest in the tribological behavior. A pin on disk sliding friction test was conducted on the titanium alloy (Ti-6Al-4V). Alloy disks were slid against the bearing ball composed of stainless steels at the speeds of 0.2 and 0.8 m/s. When the sliding speed is higher the coefficient of friction and wear rate are lower. For steel the wear rate is the least. Microstructural study confirms that Ti alloys have the tendency to transfer material to their counter face and there are possible tribological reactions. Degradation of mechanical properties of contact areas of reaction products takes place.

Keywords: Titanium, Material transfer and tribological reaction

INTRODUCTION

Titanium exhibits superior properties as a tribomaterial in comparison with aluminum and magnesium which are light weight alloys. Titanium alloys have an excellent resistance for heat and corrosion and they are much harder than Magnesium and aluminum alloys. As compared to aluminum and magnesium they have high affinity for oxygen which leads to formation of an adherent surface oxide namely titanium oxide which acts as a solid lubricant. Titanium alloys also exhibit good metallurgical, heat treatment and mechanical properties due to which it finds a lot of application in aerospace industry. Tribological concerns for Ti in aerospace componentshave focused mainly on their fretting behavior, leading to researchon surface treatments like ion implantation and solidfilm lubrication (Kustas and Misra, 1992; Waterhouse and Iwabuchi, 1985). Needs in the chemical process industry motivated a 1991 study of the galling and sliding wear behaviorof commercial-purity Ti and alloy Ti-6Al-4V (Budinski, 1991). In the Budinski (1991) experiment the best wear and friction results for Ti alloys were obtained for anodized counter-surfaces coated with MoS_2 solid-film or with polytetrafluoroethylene (PTFE), butthe abrasion

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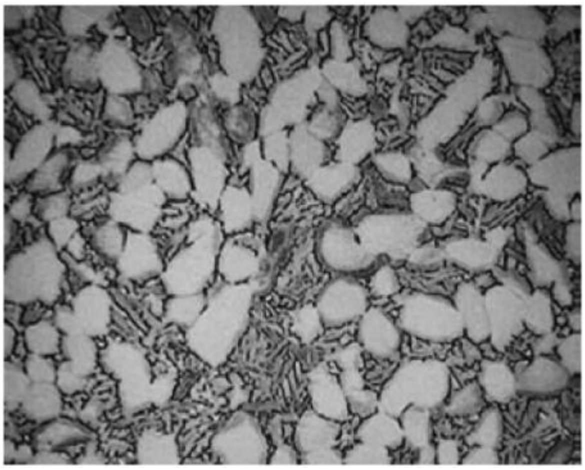
resistance was poor. Many more studies were conducted on the sliding wear mechanisms of Ti alloy. Molinari *et al.* (1997) highlighted the mechanisms responsible for the wear resistance under different load and sliding speed conditions in self-mated Ti-6Al-4V disk-on-disk sliding tests (Molinari *et al.*, 1997), and Dong and Bell (1999) reported unexpectedly high wear rates for alumina sliding against Ti-6Al-4V (pin-on-disk tests). Recent developments in Ti processing forecast the availability of lower-cost Ti and that has prompted further interestin exploring the tribological behavior of Ti alloys as bearing materials (EHKT Technologies, 2002).

EXPERIMENTAL PROCEDURE

Titanium alloy Ti-6Al-4V was tested in this study. Friction and wear tests were conducted by using pin-on-disk apparatus. Ball slider diameter was taken as 7 mm while the stainless steel was taken as a metallic materials. The disk was made up of titanium alloy of diameter 50 mm and thickness of 8.5 mm. Polishing of disk surface is done by using polishing papers while the wear tracks of an average diameter of 25 mm are used. The sliding speed was varied from 0.2 to 0.8 m/s. A 5 N normal load is applied keeping sliding distance as 350 mm. The friction force was monitored by using computerized force measurement system while the wear volumes are determined by using weight change measuring system. The wear volumes normalized by the applied load and the sliding distance of pin was defined as the wear factor.

The tests were conducted in the ambient air conditions with an average temperature of 24 ^{o}C and an average humidity of 55-60%.

Figure 1: Microstructure of Ti-6Al-4V



RESULTS AND DISCUSSION

With stainless steel the coefficient of friction fluctuates between 0.4-0.5. Due to simultaneous breakage and formation of transfer layer the fluctuation in coefficient of friction is large. The other reason can include localized fracture in transfer layer. Titanium alloy commonly transfers to thecounterface when rubbing against other metals (Budinski, 1991; Molinari *et al.*, 1997; and Dong and Bell, 1999). The surface morphology and surface analysis by using microstructures was done. Wear scar on the stainless steel was the basic identification for the formation of transfer layer. Lower coefficient of friction was observed at 0.8 m/s while the coefficient of friction was comparatively higher at 0.2 m/s.

The contact area between titanium alloy and stainless steel was observed to exhibit higher temperature which causes reduction in shear stress and lower the value of coefficient of friction. Wear rates observed are higher at both speeds of 0.2 and 0.8 m/s. Similar dependency of sliding speed is confirmed by (Dong and Bell, 1999). High wear rates occur in case of Titanium disks when sliding against stainless steels was done. Wear rates are of the order 10^{-3} mm^3/Nm. A relatively more wear is generated by harder sliders when disks of Ti were used. Dong and Bell also reported a higher wear rate of an aluminaball than that of a steel ball when sliding against a Ti64 disk (Dong and Bell, 1999). The microstructural analysis shows that the wear on the metal can be either abrasive wear or adhesive wear. Since the wear debris particles are larger and flatter at the sliding speed of 0.2 m/s in the wear process. Therefore this type of wear was termed as an Abrasive wear. On the other hand the wear debris particles at the sliding speed of 0.8 m/s were smaller with large patches of transferred material confirming that the type of wear is adhesive wear. The wear resistance of stainless steel was observed to ne inversely proportional to its hardness number. The abrasive wear of ceramics has been proposed to be a functionof both hardness and fracture toughness (Evans and Marshall, 1980). Wear resistance has a significant effect on the fracture toughness of the material. Fischer (1993) has demonstrated that, in the case of yttria stabilizedzirconia ceramics, the wear resistance increases with the fourth power of fracture toughness.

To evaluate the sliding wear the pin on disk experiment is used but if the disk is not normal to the axis of rotation it may cause vibrations to occur. It depends on the distance between the point of contact of pin and disk and the center of rotation. Catastrophic failures may occur due to plastic shearing in the materials. The catastrophic failures include cracking and crushing of the contact surfaces. The main disadvantage involves the loss of material and fragmentation of debris. Rice (1979) and Rice *et al.* (1979) have studied the wear rate and mechanism of compound impact (impact and sliding)on metals and superalloys. The material with lower fracturetoughness had a higher wear rate and gave strong evidencefor subsurface damage. Mechanically deformed surfaces usuallyhave different chemical reactivity than purely thermallystressed solids (Heinicke, 1984). The wear process of the material is affected significantly by Tribo-chemical reactions. Titanium oxides have the lower value of Gibbs free energy of formation than the value of Gibbs free energy of Titanium nitride. The main reason can be that Titanium oxides are amorphous in nature due to severe plastic deformation. Titanium aluminides were also suspected by Dong and Bell (1999) basedon the XRD analysis of the wear debris produced by aluminasliding against Ti-6Al-4V.

CONCLUSION

The titanium alloy Ti-6Al-4V was observed to exhibit excellent tribological properties while sling against stainless steel in the pin-on-disk apparatus. Fluctuations in the value of coefficient of friction occur because of simultaneous formation and breakage of transfer layer. The transfer layers are periodically formed and fractures occur in them. When the sliding speed is lower then the coefficient of friction was observed to be high with lager fluctuation and higher wear rate. Other main reasons for the high wear rate include fracture toughness and tribological properties.

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I would also like to dedicate this research work to my father late R S Mishra and mother K L Mishra.

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