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Effect of strain rate response and pin diameter on mechanically mixed layer formation and wear mechanisms in a Ti6Al4V – SS316L pair

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ABSTRACT – Three mechanisms operate during wear of materials. These mechanisms include the Strain Rate Response (SRR - effect of strain rate on plastic deformation), Tribo-Chemical Reactions (TCR) and formation of Mechanically Mixed Layers (MML). The present work investigates the effect of these three in context of the formation of MML. For this wear experiments are done on a pin-on-disc machine using Ti64 as the pin and SS316L as the disc. It is seen that apart from the speed and load, which control the SRR and TCR, the diameter of the pin controls the formation of MML, especially at higher speeds.

1. INTRODUCTION

Titanium alloys are widely used in structural applications because of its high strength to weight ratio and good corrosion resistance. Ti64 is one of the mostly used alloys of titanium [1]. Though having the aforementioned advantages, tribological behavior of titanium alloys are relatively poorer compared to other structural materials [2].

Pauschitz [3] reported that the wear behavior of materials is correlated to the type of tribo-layer formed. The formation of tribo-layer depends on sliding conditions and material pairs used, which in turn decides the wear rate. Tribolayer is generally classified into three layers 1) Transfer layer with low oxygen and same composition as that of counterface, usually appears at room temperature with softer counterface than the sliding material; 2) MML with low oxygen content, which is hard and tough, formed at relatively higher temperature in sliding systems of softer and medium hardness; and 3) Composite layer with high oxygen content, which is hard and brittle, formed at higher temperature [4].

Mao et al. [5] found that tribo layer existed on worn surfaces under various conditions. The protective role of tribo-layer depended on the presence of oxides. The tribo-layer with more oxides acted as protective layer due to its high hardness.

In the present work, experimental analysis has been carried out to evaluate the effect of the two mechanisms (SRR and TCR) in context of the formation of MML and the protection of a pin surface by MML. The effect of pin diameter on SRR, TCR and MML has been studied which is not yet reported in any of the previous studies on Ti64.

2. METHODOLOGY

In the present study, dry sliding tests were performed in a specially designed vacuum-based high temperature pin-on-disc tribometer under ambient environment in accordance with ASTM-G99 standard [6]. Ti64 alloy was used as the pin, and SS316L was selected as the disc material. This pair was selected due to their notable differences in density, thermal conductivity, hardness and crystal structure. Experiments were conducted at a constant sliding speed of $1.5 ms^{-1}$ and by using pins of different diameters (2.1, 4.6 and 6.6 mm) with normal load of 13.7, 68.7 and 137.3N respectively. A constant pressure of 2.8MPa was maintained throughout all the experiments. A combination of loads and diameter of pins ensured constant pressure. Prior to the experiments, both the pin and disc were ultrasonically cleaned in acetone for 3 minutes and then dried to remove surface contaminations. The frictional force was measured by a load cell which had the capacity of 500 N with an accuracy of ±1 N. Height loss of pin was measured using a Linear Variable Differential Transducer (LVDT) which had a maximum possible sliding distance of 4500 µm with an accuracy of ±2 µm. Detailed investigation of worn surfaces of pin and sub-surface was carried out using Scanning Electron Microscopy (SEM) (FEI ESEM Quanta 200).

3. RESULTS AND DISCUSSION

At lower diameter of pin (2.1mm), very less MML was observed at the trailing edge (Fig. 1a) and the thickness of the layer was measured to be 4-12 µm as shown in Fig. 2. It is due to low intensity of ASB/SRR and formation of TCR mix with Fe which promotes the MML. MML, observed due to the transfer of material is often accompanied with other events such as accumulation, compaction, fragmentation, oxidation due to chemical reaction with the environment, and mechanical mixing between the two sliding materials [5-7]. Formation of MML is observed towards leading edge when pin diameter is increased (5.6mm), which is shown in Fig. 1b. Layer thickness was observed to be higher at the trailing edge which gradually reduces to the leading edge (Fig. 2). This is due to the increasing possibility of entrapment of debris found at the loading edge as the diameter of the pin increased. Thickness of tribo-layer measured was 15-51µm from trailing edge to leading edge when the pin diameter was 4.6mm.

It is an interesting result that with changing the pin diameter, at same constant pressure, huge difference is observed in thickness of MML. The elevated local temperature is favorable for interdiffusion during the mixing process caused by the sliding [7]. The presence of the intermetallic phase Fe-Ti-Al confirms mechanical mixing and alloying on an atomic scale generated by the sliding wear [6,7].

At higher diameter of pin (6.6mm), thickness of MML vary from leading edge to trailing edge (9-75µm) and the whole pin is protected by MML as shown in Fig. 1c. Thickness and length of MML are higher as compared to the lower pin diameter which is due to the availability of more area for mixing the material and sufficient interface temperature [4-6].

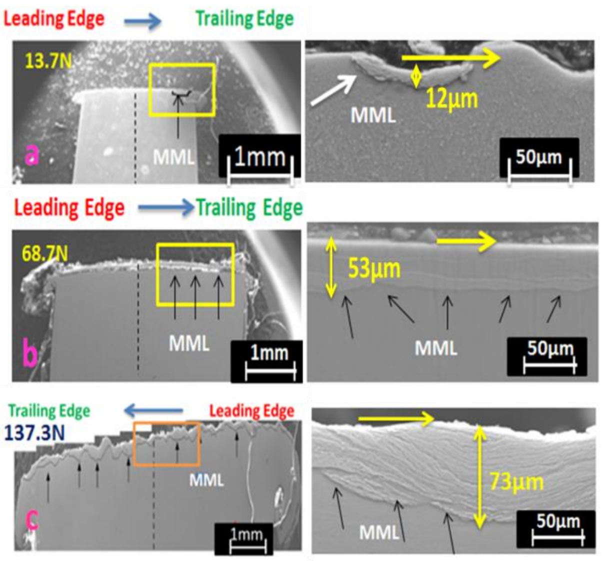

Fig. 1 SEM image of cross section of pin shows varying thickness of MML at different diameter.

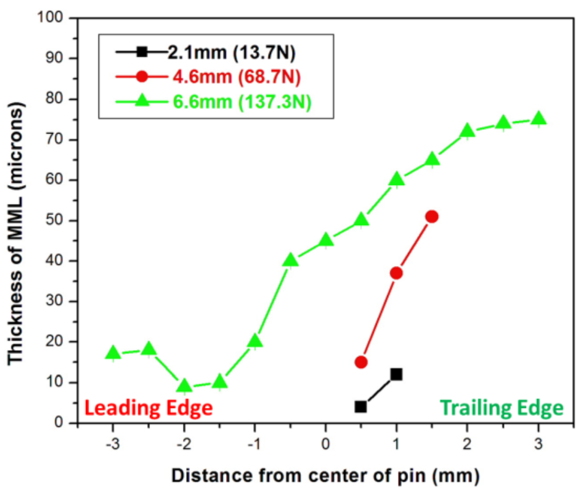

Fig. 2 Graphical representation of variation in thickness of MML from leading edge to trailing edge.

The graph in Fig. 2 shows the variation of thickness of MML with the distance from the centre of the pin. At lower pin diameter, there is less thickness of MML and is present only at the trailing edge. As we increase the size of pin to 4.6 mm, thickness of MML at the trailing edge further increases to 50 µm but still there is no MML at the leading edge. At pin size of 6.6mm, MML is present at the leading edge as well as trailing edge, but the thickness at the trailing edge is very high i.e. nearly 75 µm which gradually reduces to a minimum of 10 µm at distance of 1mm from leading edge and then again rises to 20 µm at leading edge).

4. CONCLUSIONS

1. At lower diameter of pin (2.1mm), thickness of MML is very less which is due to low contact area and formation of TCR with unstable oxide.
2. On increasing the pin diameter (4.6mm), elevated local temperature was favorable to form MML and it resulted in the increase in thickness of MML.
3. At higher diameter of pin (6.6mm), MML protected the whole surface due to presence of sufficient interface temperature and environment to form the layer.
4. It is therefore observed that the diameter of the pin controls the formation and thickness of MML especially at higher speeds, apart from speed and load which control the SRR and TCR.

5. REFERENCES

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