International Journal of Mechanical Engineering and Robotics Research

ISSN 2278 – 0149 www.ijmerr.com
Vol. 3, No. 3, July, 2014

Research Paper

DRY SLIDING WEAR OF TI-6AL-4V ALLOYS

Aadarsh Mishra[1]*

Corresponding Author: **Aadarsh Mishra ✉ aadarshm9@gmail.com*

The dry sliding wear behavior of the Ti-6Al-4V alloy sliding against itself and AISI M2 steel was investigated at different sliding velocities (between 0.2 and 0.7 m/s) and applied loads (between 30 and 200 N). Two wear mechanisms were identified, irrespective of the counter face and applied load oxidation wear at the lowest sliding velocities 0.2-0.7 m/s. Wear rate was higher against the AISI M2 at the lowest sliding velocities, and it continuously decreased as sliding velocity was increased. On the other hand, as the sliding velocity was increased it first decreased, experienced a minimum and then became very severe in the case of sliding against the Ti-6Al-4V alloy. The friction-stir processing (FSP) method was also employed to the surface modification of Ti-6Al-4V alloy applying different processing parameters. The defect-free friction-stir processed surface layers with ~1.5 mm thickness, with final micro structures of β-regions with acicular-α and GB-α, or Martensite- ά phase, were obtainable. At the lowest sliding velocities, the AISI M2 counterface exerted an abrasive effect on the Ti-6Al-4V alloy, thus accelerating its oxidative wear. At the highest sliding velocities, metallic delamination which developed through the formation of a mechanically mixed layer (MML) on the surface was the controlling wear mechanism and the thermal effects connected with the frictional heating became of primary importance.

Keywords: Ti alloys, Sliding wear, Oxidative wear, Delamination wear, Mechanically mixed Layer, Friction-stir processing, β-regions, Wear performance, Surface modification

INTRODUCTION

The wear behaviour of a sliding system depends onmany factors, including the properties of the specimen and counter face materials, their interaction with the environment and the experimental conditions. A careful characterization of the sliding wear mechanisms of metal alloys has been carried out on steels, aluminum alloys and aluminium-base metal-matrix composites (MMC). At higher loads the contribution of delamination increase and, correspondingly, the wear rate also increases.Ti-6Al-4V alloy is the most frequently and successfully used as $\alpha + \beta$. Titanium alloy in various industries

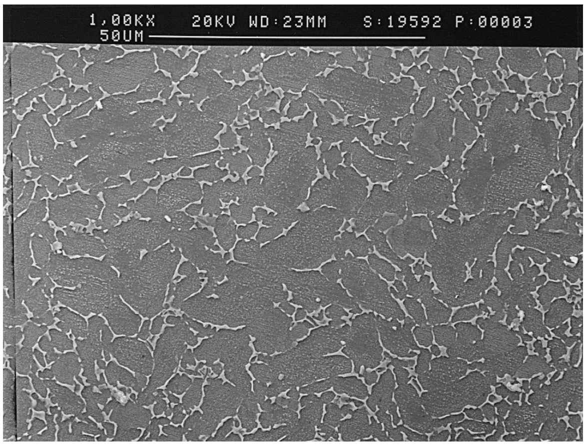
[1] Department of Mechanical Engineering, Manipal Institute of Technology, Manipal University, Eshwar Nagar, Manipal, Karnataka-576104.

due to its many favorable properties, including its high strength to weight ratio, low density and biocompatibility. Nevertheless, Ti-6Al-4V alloy has poor surface wear properties when used in some harsh environments. It limits the product service life in mechanical friction engineering and transmission components for human body, such as hip implants. For many applications it is sufficient or even desirable to reinforce only a surface layer while the other part of the component retains its original composition and structurewith high toughness. Considering that the wear performance dependson the surface layer, rather thanthe bulk alloy, the surface modification could provide a solution to allow the longevity enhancement of Ti-6Al-4V alloy products. Friction-stir welding and processing as an emerging solid state joining and manufacturing technique, has already attracted considerable attention in multiple industries due to its unique process advantages and high success for joining/ processing of many Al and Mgbased light alloys.Titanium alloys are of increasing importance in applicationswhere high strength and low density are of primary importance. They are, however, usually reported to possess a low sliding wear resistance because of their low resistance to plastic shearing and the low protection exertedby the surface oxides . Because of this, many surface modification treatments are under continuous development to improve the wear resistance of these alloys in specific tribological conditions. The acting wear mechanisms during the dry sliding wear of titanium alloys, however, have not been carefully addressed and a precise understanding of the dry sliding wear behaviour of the sealloys, as in the case of steels or aluminium alloys, has not yet been achieved. Further, work is therefore needed to clarify the effect of the tribological parameters, including applied load, sliding speed and counter face material, on the sliding wear mechanisms of these alloys, in order to beable, inter alia, to better rationalize the effects of the surface modification treatments, and eventually correctly propose new types of treatments. The prepared surface layer with new micro structure feature by FSP is very considerable in thickness so that it even can be up to centimeters. More importantly, other than the melting solidification surface treatment methods, such as laser cladding, the solid-state FSP procedure can prevent some metallurgical defects including cracking, porosity, anisotropic and dendritic grain coarsening, and excess residual stress after the fusion-re-solidification procedures. In addition, the productive efficiency of FSP is very considerable on the premise of lowcost. Thus, the afore mentioned technical advantages of FSP strongly motivated. The research interests on metallic surface modification via this method.

EXPERIMENTAL PROCEDURE

The material studied was a Ti-6Al-4V alloy (chemical composition in mass percent: Ti-6.1% Al-3.95% V, 0.15%Fe, 0.14% O, here after code named Ti-64. The material was received in the form of a cold rolled bar with an average hardness of 250 HV 10. The micro structure of thealloy is shown in Figure 1. The discs for wear testing had a diameter of 35 mm and a thickness of 8 mm, and were machined from the bar with the axis parallel to the rolling direction.

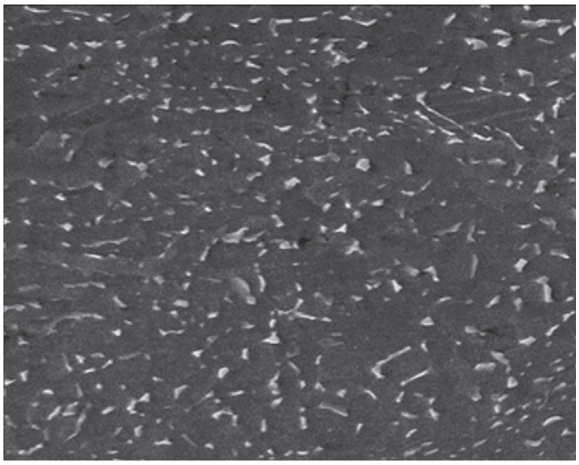
Figure 1: Micro Structure of the Alloy Under Study



Sliding tests were carried out in a disc-on-disc configuration and pure sliding was obtained by keeping the counter face disc fixed. The tests were performed at 40, 80 and 120 N and within a sliding velocity range of 0.2-0.7 m/s. The sliding distance was about 1560 m, which proved to be sufficient to attain asteady-state condition. Three-millimeter-thick rolled plates of Ti-6Al-4V alloy (Ti-6.1% Al-3.95% V, 0.15%Fe, 0.14% O), with $\alpha + \beta$ duplexphases after annealing treatment, were used as substrates in the experimental work. FSP procedures were performed using a professional FSW machine with an FSP tool of WC-13 wt.% Co matrix material. The control mechanism of the FSW machine was adopted as 'position-control' mode. The FSP toolwas composed of a cylindrical shoulder with 10 mm in diameter and a pin in the shape of circular truncated cone. The surface of shoulder was flat in shape. The pin was shaped as circular truncated cone, and was tapered from 5 m min diameter at the root to 3 mm in diameter at the pin tip. The pin length was 2.00 mm to produce an FS-processed surface layer on the substrate with a thickness of slightly more than 2.0 mm.

During the FSP procedures, a specialized gas protection device with a gas chamber fixed on the work operating platform was utilized to continuously introduce a shielding atmosphere of argon gas (99.5% purity) into the chamber. Furthermore, an infrared temperature measurement system was applied to monitor the temperature changes of the substrate surface during FSP on Ti-6Al-4V alloy plates, aiming to investigate the thermal histories and cooling rates of the FSP procedures.

Figure 2: Microstructure of BM by SEM



The wear mechanisms were investigated by a carefulanalysis of wear debris, worn surfaces and the sub-surface damage using scanning electron microscopy (SEM). And XRD measurements with Cu-Karadiation.

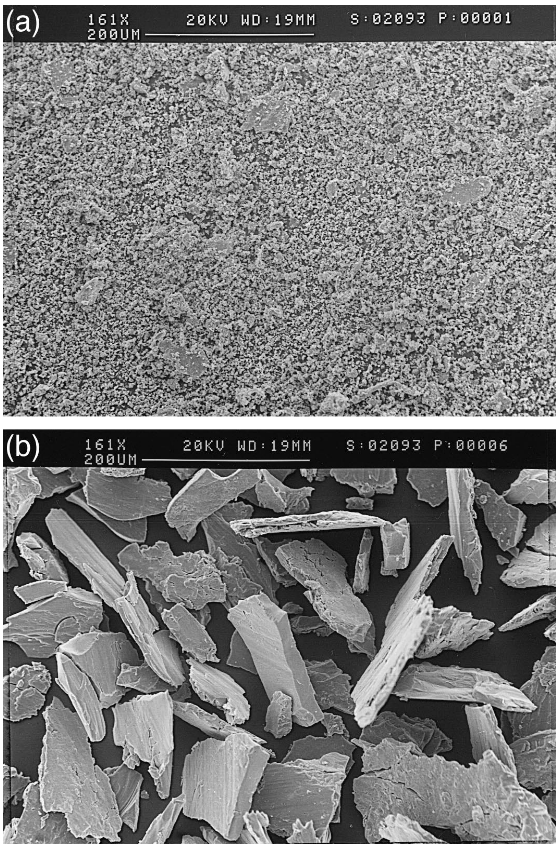
RESULTS AND DISCUSSION

Wear Rate

In the case of the Ti-64 alloy sliding against itself, the counter face disc also experienced considerable wear.The wear rate of the counter face is plotted as a function of the sliding velocity. In the case of the test at 120

N, the observed wear rate increases as the sliding velocity is increased although a plateau is present at about 0.2-0.7 m/s. At 80 N the wear rate first increases and then displays a minimum. At 40 N, finally, it is little dependent on the sliding velocity. On the other hand, the AISI M2 counter face disc experienced negligible wear during the sliding tests_two orders of magnitude lower than in the case of the Ti-64 counter face. and no specific trends with the tribological parameters can be highlighted. It is therefore confirmed that it contributes to a minimal extent to the wear of the tribological system.

Figure 3: a) SEM Micrographs of Debris Produced at 80 N and at 0.2 m/s. and 0.7 m/s. (b) in the Case of Testing Against the AISI M2 Counter Face

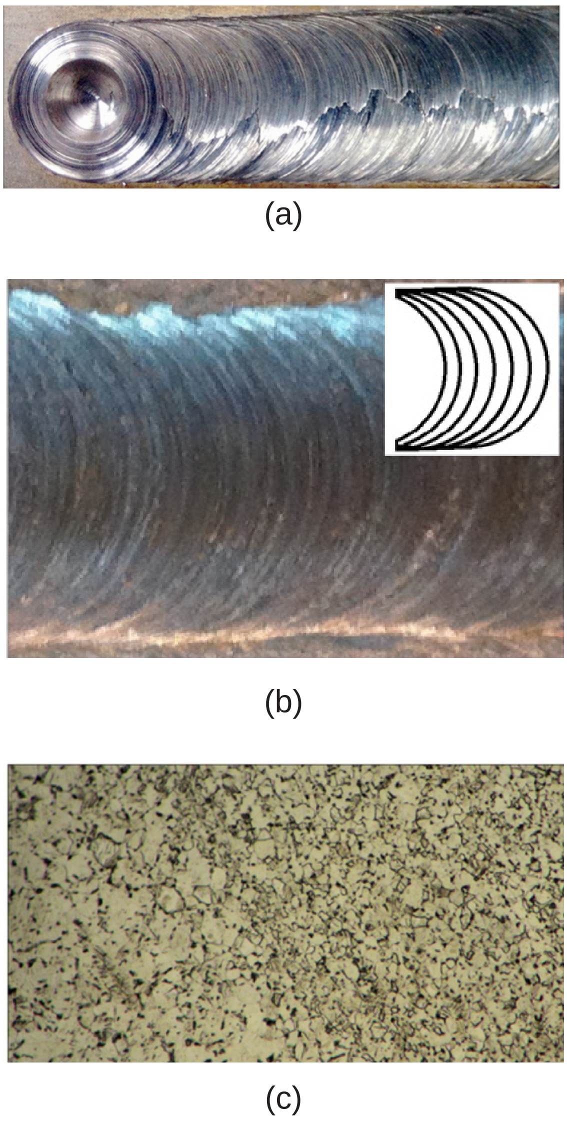


Surface Macroscopic Formability and Cross-section Macro Structure

The rotating tool was slowly inserted into the substrate on the center line. Thus, the localized heats were generated due to the friction between the interface of tool and substrate. After the rotating tool-shoulder fully contacted with the substrate surface, the tool travelled along the center line at a certain speed. During the rotating and traveling of tool, the tool behaviour of friction and stirring was maintained to generate heat-input into the FS processed zone and induce the severe plasticization of the Ti-6Al-4V alloy. Infact, during the tool traveling, the main heat resource included not only the friction heating but also the plastic-deformed energy releaseof the matrix itself. Thus, a long strip of FS processed zone was producedon the substrate via a single-pass FSP procedure after the translational motion of the rotating tool. For the metallic surface modification, the FS processed zone was then the produced surface layer, with a thickness of slightly more than pin length. A key-hole was remained at the final position of FSP pass after the elevating of tool-pin.

Figure exhibits the microscopic top view of the single-pass FS processed surface layer, using the n value of 250 r/min and v value of 50 mm/min. Numerous ring-like textures and unilateral surface crowns were presented. When the v was increased, or the n was decreased, the surface crowns disappeared. It was also one of results from process optimizations. During FSP, the Ti-6Al-4V alloy under went severe plasticized deformation because of the tool rotating and travelling behaviours at the heat elevating situation. Thus, the softened and then severely plasticized material ahead the travelling tools houlder was migrated from the front at the advancing side (AS, where the tool rotating direction was the same with the travelling direction) to the rear at the retreating side.

Figure 4: Top view of the FS processed surface layer with surface crowns (a) and without surface crowns using a tailored λ value (b); typical cross-section view of the FS processed surfaceLayer (d) RS

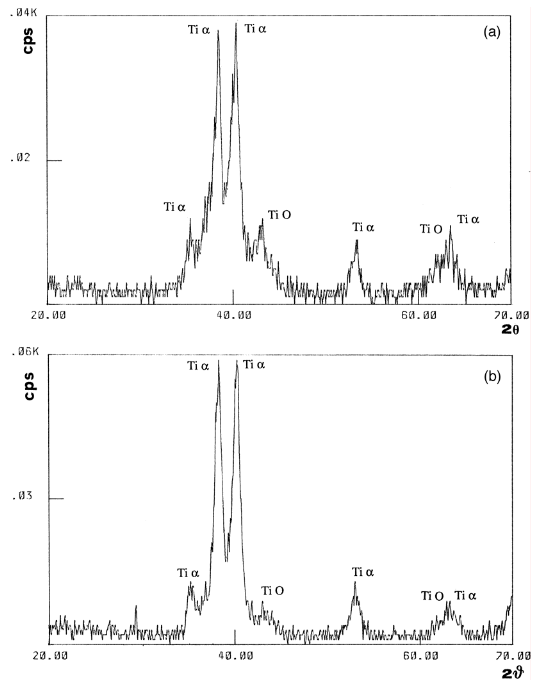


The relationship of λ and FSP processing parameters was stated as λ =v/n; where v is the tool traveling speed and n is the tool rotating speed.

Analysis of Wear Debris

The characteristics of the wear debris and surface and sub-surface damage in the case of the Ti-64 alloy sliding against itself were reported. Here the analysis is therefore focused on the case of the Ti-64 alloys sliding against the AISI M2 counter face. In particular, reference to the test at 100 N will be made, in order to facilitate comparison of the results. The morphology of the debris collected at the end of the tests at 0.2 and 0.7 m/s, i.e., at the two extremes of the sliding velocity range, are shown. The XRD spectra

Figure 5: XRD Spectra of Debris Produced at 80 N and at a) 0.2 and b) 0.7 m/s in the Case of Testing Against the AISI M2 Counterface



of the debris collected at the end ofthe tests at 0.2, 0.5 and 0.7 m/s are shown in Figure. It can be clearly noted that at the lowest sliding velocity they are constituted for the most part by a mixture of TiO and a-Ti. As the sliding speed is increased the fraction of the oxides decreases and, on the other hand, the proportion of metallic a-Ti constituent increases. Thus, the big plates are metallic in nature,although they may also contain some TiO compacte particles.

CONCLUSION

In the present investigation the dry sliding wear behaviour of the Ti-6Al-4V alloy sliding against itself and an AISI M2 steel was investigated. The sliding velocities ranged from 0.2 to 0.7 m/s and the applied load between 40 and 120 N. With a further increase in the sliding velocity a change in the wear mechanism was observed, since the contribution of metallic delamination continuously increased and at 0.7 m/s, essentially only delamination wearwas present in both couplings. This behaviour was attributed to the different temperatures which were reached on the contacting surfaces during sliding. In particular, the experimental wear rates at 0.7 m/s were found to be directly related to the surface temperatures, thus showing the importance of thermal softening effects. Moreover, The defect-free FS processed surface layer of the Ti-6Al-4V alloy was obtainable by the applied processing parameters. A suitable ratio value (λ) of the tool travel speed (v) to tool rotation speed(n) benefited the formability of well-distributed ring-like textureson the processed surface pass. Peak processing temperaturesof FSP procedures exceeded the β Transus. The elevatedtool rotating speed resulted in a higher FSP peak processing temperature. The cooling rate through the Ms was accelerated with the increase of tool travel speed.

ACKNOWLEDGMENT

I would also like to dedicate this research work to my father Late R S Mishra and mother KL Mishra.

REFERENCES

1. A Molinari, G Straffelini, B Tesi and T Bacci (1997), Wear, Vol. 208, pp. 105-112.
2. F H Stott, J Glascott and G C Wood (1985), Proc. R. Soc. London, Ser. A Vol. 402, pp. 167-186.
3. G W Stachowiak and A W Batchelor (1993), *Engineering Tribology, Elsevier, Amsterdam*.
4. K G Budinski (1991), Wear, Vol. 151, pp. 203-217.
5. S Venkatesan and D A Rigney (1992), Wear, Vol. 153, pp. 163-178.
6. S Yerramareddy and S Bahadur (1992), Wear, Vol. 142, pp. 253-261.
7. T Bell, H W Bergmann, J Lanagan, P H Morton and A M Staines (1986), “Surf. Eng.”, Vol. 2, pp.133-143.
8. T S Eyre and H Alsahin (1997), “Proc. Int. Conf. on Wear of Materials”, *ASME, New York*, pp. 344-350.