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Reciprocating Wear Characteristics of Surface Modified Ti64 Alloy under Variable Load

Abstract

The surface of the Ti64 alloy was modified by ultrasonic shot peening technique to nano-structure. This was done to enhance the tribological properties of the alloy. The new surface formed was investigated for reciprocating wear performance against the AISI52100 tribo-pair. An increase in surface hardness was found in the case of the shot-peened sample in comparison with a non-ultrasonic shot-peened sample. The microhardness was measured using the Vickers hardness test. The tribological test was carried out for both samples with different loading conditions. SEM, EDX of the worn surface, was carried out to know the mechanism of wear. It was found that the wear resistance was improved due to shot peening.

Keywords: Friction;wear;composite; titanium alloy; lubrication

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Introduction

The growing need for materials with strength/weight ratio at high temperature and applied force for aerospace applications increases the demand of Ti-based composites. Pure Ti and its alloy are used commercially in the aerospace industry due to lightweight (low density of about 60 % to that of steel), high strength and excellent corrosion resistance. Most widely used Ti alloy is Ti64 (Ti-6Al-4V) [Chen KM et al.2015, Kumar S et.al.2017]. Ti64 can be used for air-frame, engine parts; apart from this, it can also be used for manufacturing blades, discs, rings, fasteners, vessels, cases, hubs, or in forged parts and biomedical implants [Kumar S et.al.2016]. However, there are some limitations of these materials due to their poor tribological properties and hardness [Hu ZY X et.al.2017, Dixit T, Singh I, Prasad KE.2018]. Various processes like laser shock peening [Ye C, Liao Y, Suslov S, Lin D, Cheng GJ.2014], shot peening [Child DJ, West GD, Thomson RC.2011], ultrasonic peening [Amanov A, Cho IS, Pyoun YS, Lee CS, Park IG.2012], laser-assisted ultrasonic nanocrystal surface [Liu J, Suslov S, Ren Z, Dong Y, Ye C.2019], surface mechanical attrition treatment are used for enhancing the mechanical properties through surface modification of materials at the nano level. Various researches have been done to improve the surface property of Ti64 [Maire L, Faure L, Philippon S, Novelli M, Marcos G, Czerwiec T.2015].

In the present investigation, the hardness, average coefficient of friction (COF) variation, wear resistance of un-shot peened as well as shot-peened Ti64 samples at different loads were studied.

Experimental Section

The alloy Ti–6Al–4V was procured from M/s Mishra Dhatu Nigam Limited, Hyderabad, as hot rolled and annealed rod of 50 mm diameter. The chemical composition of the alloy is recorded in Table1. The batch contain two sample one without shot peening (Ti64) and one with ultra-sonic shot peen (Ti64USSP). The sample bar of Ti-6Al-4V was cut into 20mm X 15 mm cylindrical bar, and the surface was polished with various grades of emery paper followed by cloth polishing with alumina and diamond paste. Disc of 20mm (Diameter) X 15mm (thickness) were sectioned from the sample rod and subjected to ultrasonic shot peening using Stress Voyager (SONATS). This system works on the acoustic assembly, which creates mechanical vibration, and this is transfer to hard balls of 100C6 grade steel. The vibration is transferred from steel ball to specimen surface, which is kept in the horizontal position to have uniform shot peening on the surface, while the frequency is set at 20 kHz. Vickers test was carried out on both samples under a normal load of 1kgf (9.807N) with a 10 sec holding time. Nine indentations were carried taken, and diagonals were measured using a digitally calibrated objective. An increase in surface hardness was observed as 334HV for shot-peened samples, while for un-USSP, it was 301HV.

Both polished Ti6Al4V samples (Ti64USSP and Ti64) were subjected to Dry sliding reciprocating tests in ambient temperature and humidity, against AISI52100 steel ball (6 mm diameter) as counter body using a wear tester (Rtec multipurpose tribometer) for 20 minutes. The frequency of 5 Hz, the stroke length of 1mm, and loads of 10,15, 20, and 25 N were applied on the ball, where the platform was reciprocating, and the ball was kept stationary. The wear volumes of the flat test samples were measured using with a vertical scanning interferometer Rtec multifunctional tribometer and image processing software. The specific wear rate (in mm^3/Nm) was calculated from wear volume (mm^3) for all loading conditions. SEM and EDX were done to analyze the wear mechanism.

Table 1. Chemical composition of the Ti–6Al–4V alloy (wt.%).

Al	V	C	O	N	H	Fe	Ti
6.24	4.11	0.015	0.163	0.004	0.005	0.040	Balance

RESULTS AND DISCUSSION

The variation of average COF and wear rate is shown in figure 1. It can be observed from fig.1(a) that there is an increase in average COF with the load for un-USSP Ti64 till 20N and a slight decrease in the value of COF is observed after that. For Ti64USSP sample, the variation is fluctuating with the load increasing for 10N and 20N while decrease for15N and 25N. The average COF was found to be lower in the case of USSPed samples for all the loads. The overall lowest COF was seen for 25N in Ti64USSP sample. From fig.1(b), it can be seen that there is an increase in wear rate from 10N to 15N for both Ti64/Ti64USSP with a decreasing trend till 25N for Ti64 but not the similar trend is observed for Ti64USSP. Wear rate is observed to lower for the USSPed samples for all the loads except at 25N. The lowest wear rate was seen at 10N for Ti64USSP sample. Grooves along with debris are visible for 10N and 25N Ti64USSP. Groves marks are clearly visible, surface cracks, and brittle fracture which can be noticed more prominently in 25N of USSPTi64.

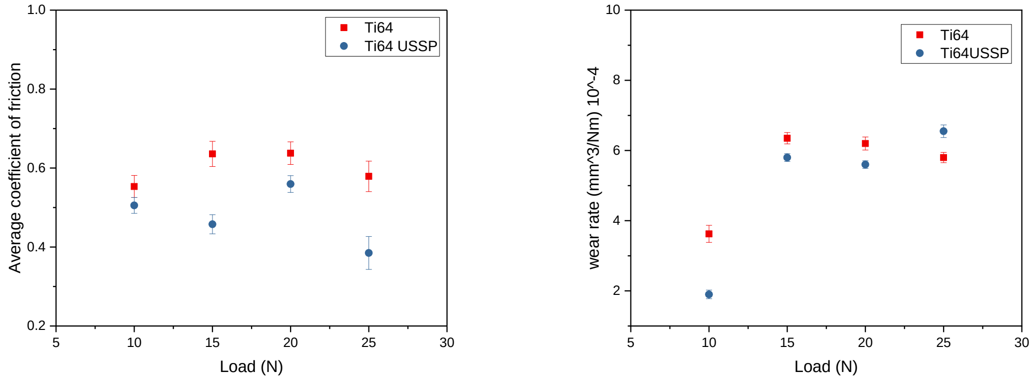
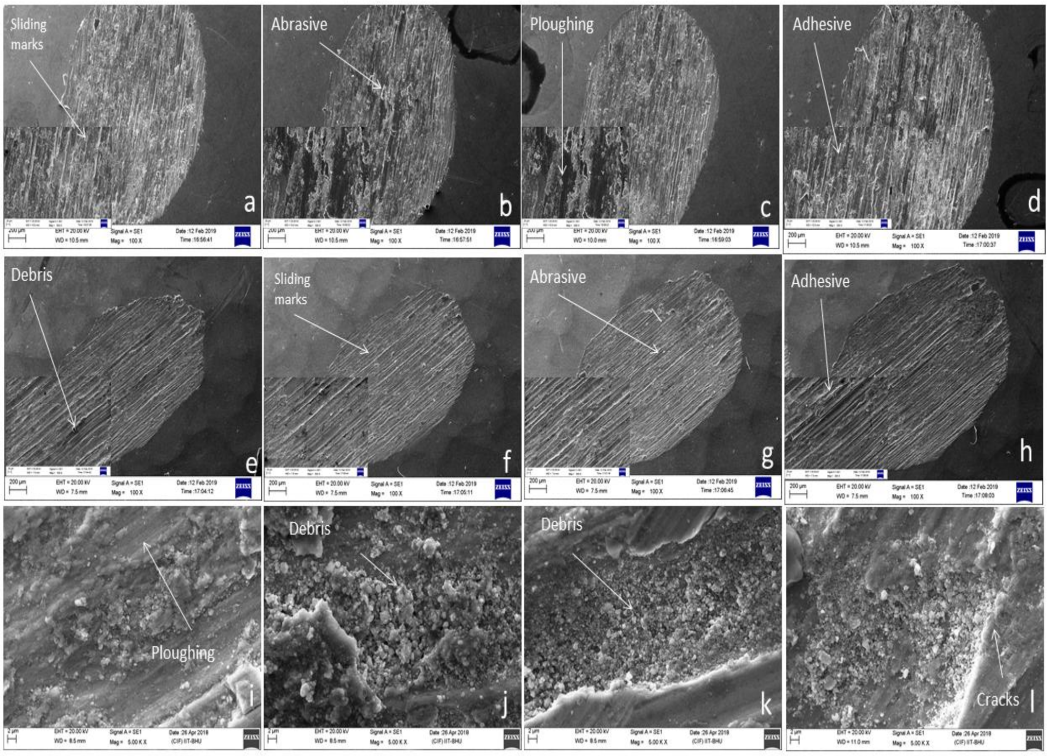


Fig 1(a).Show the variation of average COF with the load. 1(b). show the variation of wear rate with the load.



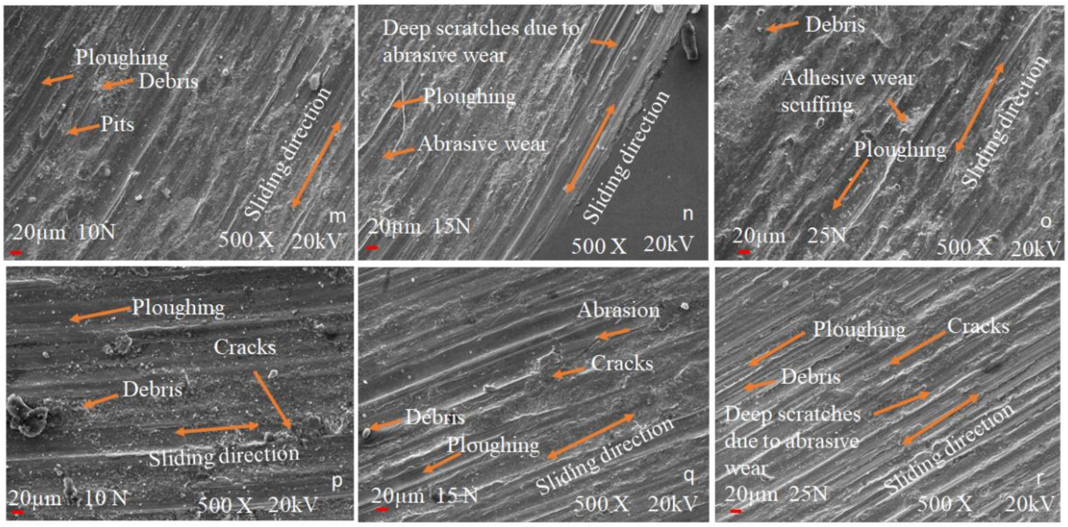


Fig 2. SEM images of Ti64USSP (a,b,c,d,i,j,m,n,o) and Ti64(e,f,g,h,k,l,p,q,r) for 10N fig 2(a,e,m,p) 15N fig 2(b,f,n,q), 20N fig 2(c,g), 25N fig 2(d,f,o,r), fig 2 (i,j,l,k) shows the magnified view of worn surfaces at 10 and 25 N for both Ti64USSP and Ti64 samples.

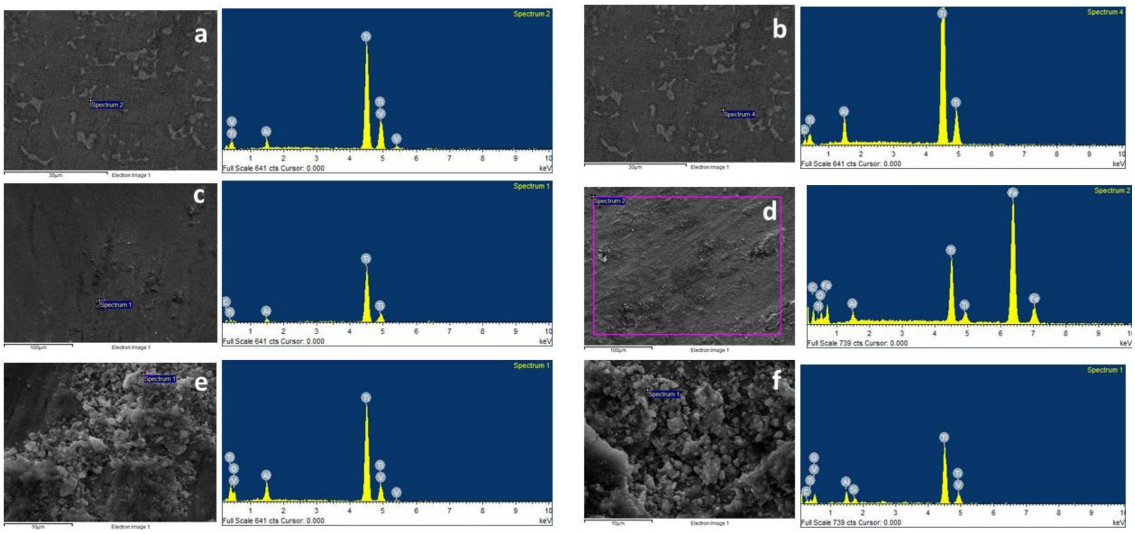


Fig 3. EDX of counter body (a,b) base sample(c,d) and Worn Surface(e,f).

Fig 1(a).Show the variation of average COF with the load. 1(b). show the variation of wear rate with the load.

Fig 2 shows the wear micrograph at the various loads of Ti64 and Ti64USSP samples. In fig 2.(a,e, m ,p) for 10 N the sliding marks and grooves can be seen in Ti64/Ti64USSP. In fig 2(b,f,n q) for 15N, these groves become deep, and sliding marks are more prominent. A similar trend is observed in micrographs of 20N in fig.2(c,g) ploughing, abrasive wear marks, and cracks are visible. In fig.2(d,h,o,r) the cracks are more prominent for both samples.

From fig 2. (i,j) for 10N and 25N Ti64 sample, we can see it can be seen that debris is spread everywhere on the worn surface. From fig 2. (k,l) microcracks and deep. From fig 3.(a,b) presence of the white region indicates the formation of the oxide surface, which is clearly visible in SEM micrographs. Furthur it is verified by EDX of the surface which shows the oxygen content. In Ti64 the wear is more at 10N due to abrasive wear and no surface layer compaction of debris, while material removal in Ti64USSP is less due to ploughing, surface hardening, and surface layer compaction clearly visible SEM images. From fig 3.(c,d) the counter body shows the transfer of material from the samples to ball i.e presence of specimen debris on the ball. EDX of the ball also shows the peak of C, Fe, and O along with base material. In EDX the peaks of Ti, V, Fe, O, Al, and C can be seen on the worn surfaces and a similar observation was reported elsewhere [Euh K, Lee J, Lee S.2001, Chen G, Jiao Y, Tian T, Zhang X, Li Z, Zhou W.2014, Revankar GD, Shetty R, Rao SS, Gaitonde VN.2017]. It indicates the formation of the oxides on the surface of samples creating a protective layer for further wear of surface. From fig 3.(e,f) the nature of debris as particles can be seen. The presence of both specimen and counter body in the debris is shown by EDX of the materials and few O peaks indicated that the oxidation of the particles.

The hardness of the Ti64USSP sample in comparison to Ti64 samples is high, measured on Vickers microhardness tester. USSP is used to refine the grain structure which causes the stress on the treated surface is more severe than the inside layer up to some micron and induce work hardening phenomena to increase the microhardness of Ti64USSP. There is an increase in wear resistance of the surface and the hardness of the USSP sample.

Surface hardening can increase the performance of the sample. The COF is low for Ti64USSP samples at all loading conditions while the wear rate is low till 20N with a slight increase with load at 25N. This increase in wear of Ti64USSP is may be due to the breaking of the oxide layer and brittleness of the surface exposing the inner layers at high load. In fig.2(r) it is visible from the SEM micrographs at 25N for Ti64USSP revealing the dominant mechanism of wear and increase in the wear rate. There is no pattern observed with an increase in load for both samples. The Ti64USSP sample has improved wear and friction properties in loading condition at 10,15, and 20N, but at 25N the wear is slightly high may be due to the strain hardening of the material makes the surface more brittle and forces are high enough to break the tribolayer causing loss of materials which does not happen for Ti64 while due where ploughing is dominant which result in plastic deformation of material rather than breaking the tribolayer. The COF is minimum for the USSP sample at 10N while increasing a little at 25 N because of the breakage of tribolayer and deep scratches due to abrasive mechanism is dominant at higher load and these abrasive scratches cause the failure.

Conclusion

USSP is used to refine the grain structure and causes work hardening to increase the microhardness of Ti64. There is an increase in wear resistance of the surface due to an increase in the hardness of the USSP sample. The wear rate, in general, decreases for the USSP sample, however, it increases a little at 25 N because of ploughing and abrasive wear. The Ti64USSP sample has improved wear and friction properties in loading conditions at 10,15,20 and 25N. The dominant mechanism of wear is a combination of abrasive and adhesive along with ploughing.

References

Amanov A, Cho IS, Pyoun YS, Lee CS, Park IG.2012. Micro-dimpled surface by ultrasonic nanocrystal surface modification and its tribological effects, Wear. 286–287: 136–144. doi:10.1016/j.wear.2011.06.001.

Chen G, Jiao Y, Tian T, Zhang X, Li Z, Zhou W.2014. Effect of wet shot peening on Ti − 6Al − 4V alloy treated by ceramic beads, Trans. Nonferrous Met. Soc. China. 24: 690–696. doi:10.1016/S1003-6326(14)63112-5.

Chen KM, Zhou Y, Li XX, Zhang QY, Wang L, Wang SQ.2015. investigation on wear characteristics of a titanium alloy/steel tribo-pair, Mater. Des. 65: 65–73. doi:10.1016/J.MATDES.2014.09.016.

Child DJ, West GD, Thomson RC.2011. Assessment of surface hardening effects from shot peening on a Ni-based alloy using electron backscatter diffraction techniques, Acta Mater. 59: 4825–4834. doi:10.1016/j.actamat.2011.04.025.

Dixit T, Singh I, Prasad KE.2018. Room and high temperature dry sliding wear behavior of Boron modified as-cast Ti-6Al-4V alloys against hardened steel, Wear. 0–1. doi:10.1016/j.wear.2018.10.021.

Euh K, Lee J, Lee S.2001. Microstructural modification and property improvement of boride/Ti-6Al-4V surface-alloyed materials fabricated by high-energy electron-beam irradiation, Metall. Mater. Trans. A Phys. Metall. Mater. Sci. 32: 2499–2508. doi:10.1007/s11661-001-0039-4.

Hu ZY, X, Cheng W, Li SL, Zhang HM, Wang H, Zhang ZH, Wang FC.2017. Wang, Investigation on the microstructure, room and high temperature mechanical behaviors and strengthening mechanisms of the (TiB+TiC)/TC4 composites, J. Alloys Compd. 726: 240–253. doi:10.1016/J.JALLCOM.2017.08.017.

Kumar S, Chattopadhyay K, Mahobia GS, Singh V.2016. Hot corrosion behaviour of Ti–6Al–4V modified by ultrasonic shot peening, Mater. Des. 110 : 196–206. doi:10.1016/j.matdes.2016.07.133.

Kumar S, Chattopadhyay K, Singh V.2017. Effect of ultrasonic shot peening on LCF behavior of the Ti e 6Al e 4V alloy. J. Alloys Compd. 724: 187–197. doi:10.1016/j.jallcom.2017.07.014.

Liu J, Suslov S, Ren Z, Dong Y, Ye C.2019. Microstructure evolution in Ti64 subjected to laser-assisted ultrasonic nanocrystal surface modification, Int. J. Mach. Tools Manuf. 136 : 19–33. doi:10.1016/j.ijmachtools.2018.09.005.

Maire L, Faure L, Philippon S, Novelli M, Marcos G, Czerwiec T.2015. Influence of duplex USSP / Nitriding surface treatments on the dry sliding behavior of Ti6Al4V / AISI 316L tribopairs, Procedia Eng. 114 (2015) 621–626. doi:10.1016/j.proeng.2015.08.113.

Revankar GD, Shetty R, Rao SS, Gaitonde VN.2017. Wear resistance enhancement of titanium alloy (Ti-6Al-4V) by ball burnishing process, J. Mater. Res. Technol. 6: 13–32. doi:10.1016/j.jmrt.2016.03.007.

Ye C, Liao Y, Suslov S, Lin D, Cheng GJ.2014. Ultrahigh dense and gradient nano-precipitates generated by warm laser shock peening for combination of high strength and ductility, Mater. Sci. Eng. A. 609 : 195–203. doi:10.1016/j.msea.2014.05.003.