Characterisation of Ti-6Al-4V Reciprocating Sliding Wear Test Behaviour

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Abstract. Sliding contact will experience wear in majority of mechanical components during their service life where it reduces the performance of the components. The capability to predict the evolution of reciprocating wear scars, such as the scar's width and depth, would be a valuable tool when designing mechanical components. Wear scar mechanism behaviour is characterised during stabilized cycle reciprocating sliding wear test of Ti-6Al-4V investigated using pin-on-flat arrangement under variable duration of sliding. The test samples were analyzed using profilometer test, optical microscopy test, Scanning Electron Microscopy (SEM) test, Energy Depressive X-ray (EDX) test and Vickers Hardness (HV) test. Stabilised high number of cycles shows low wear rate and initiation period of low cycles produced higher wear rate.

1. Introduction

Sliding friction generally occurs whenever moving parts are present [1]. Sliding phenomena widely will experience wear in most majority of mechanical components during their service life where it reduces the performance of the components. Whenever lubricated or dry sliding, there is evidence that substantial work-hardening occurs at the worn surface [2]. In dry sliding condition, a high compressive pressure and large shear strains in the asperities were produced [3].

The phenomenon of characterisation of reciprocating sliding wear test conditions in the presence of cyclic load on multiple specimen was widely reviewed by researchers. There are also several studies have been done in this direction for various materials of wear behavior characterisation [4]. The capability to predict the geometry of reciprocating wear scars, such as the scars width and depth, would be a valuable tool when designing mechanical components. The wear mechanism or characteristic in reciprocating sliding condition are complex as various fundamental phenomena needed to be considered [5].

Kapoor was concluded that the plastic rachetting/ sliding occurs when a material is repeatedly loaded above yield. The plastic deformation and wear rate increased with the duration of cycles. Meanwhile, the study has mentioned that reducing the coefficient of friction to zero does not help in stopping wear because the mechanism are driven even frictionless sliding/ rolling [6]. The sliding wear characteristic under stabilised high number of cycles is the focus of this study.

2. Experimental Method

2.1 Specimen preparation

Titanium Alloy (Ti-6Al-4V) is widely used in aeroengine application, due to their excellent properties combination of high melting point, high strength, low density, high corrosion resistance and biocompatibility [7]. However, many investigations have shown that the failure of performance is because of wear and friction [8]. Hence, to improve their application performance Ti-6Al-4V will be used in this study. Ti-6Al-4V specimens machined into two different shapes. The upper specimen, cylindrical rod of 25 mm length with one edge of the cylindrical rod is rounded to form a

hemispherical cap with radius of curvature Ø12 mm and the flat specimens are known as lower specimens made of rectangular blocks of nominal dimension 100 mm x 25 mm x 8 mm. The dimension selected to fit in with the wear test machine.

2.2 Reciprocating sliding wear test

The experiment is done using the tribometer pin-on-flat machine by Ducom Triboinnovaters in dry condition at ambient air shows in Fig. 1. The pin is placed in the upper specimen holder meanwhile the flat specimens placed in the lower specimen holder. Both specimens are clamped and the normal load is applied to the pin. As the pin remains static condition the flat bar will have a linear sliding past the upper specimen. Table 1 shows the test parameter that has been running for the test experiment.
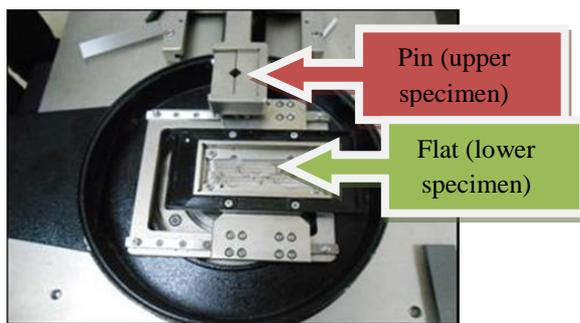
Table 1: Testing parameters

Fig. 1: Flat and pin specimen are placed

Normal load, P (N)	200
Duration, s	4200, 12600
Speed of motor, RPM	100
Diameter pin size, mm	12

2.3 Microstructure characterisation

Before testing, specimens were cleaned with ethanol to remove dust from the surfaces. In order to evaluate the wear track width and depth, profiles are measured along each reciprocating sliding wear track with an advanced 3D optical microscope. The microstructure of wear track is measured with 2D optical microscope. Finally, to determine the hardness of the wear's region Micro Vicker's hardness-tester is used. The load is set at 980.7 mN (HV0.1) and indented to the surface for 5 s at three different areas which are unworn, worn and some black spot on the wear surface.

3. Results & Discussions

3.1 Coefficient of friction

Representative plots of the coefficient of friction (COF) for different duration of reciprocating sliding are shown in Fig. 2 a. The COF suddenly jump until value 0.257 after about 1 s. The average COF for the reciprocating sliding results is 0.275 and it remains stable until the end of testing which it under low wear regime [9]. Finding by [10] shows that in excess of 0.25 friction of coefficient with the presence of plastic deformation on the wear surface. After the end of testing, it can clearly be seen that all the debris gathered out from the sliding wear track shows in Fig. 2 b.
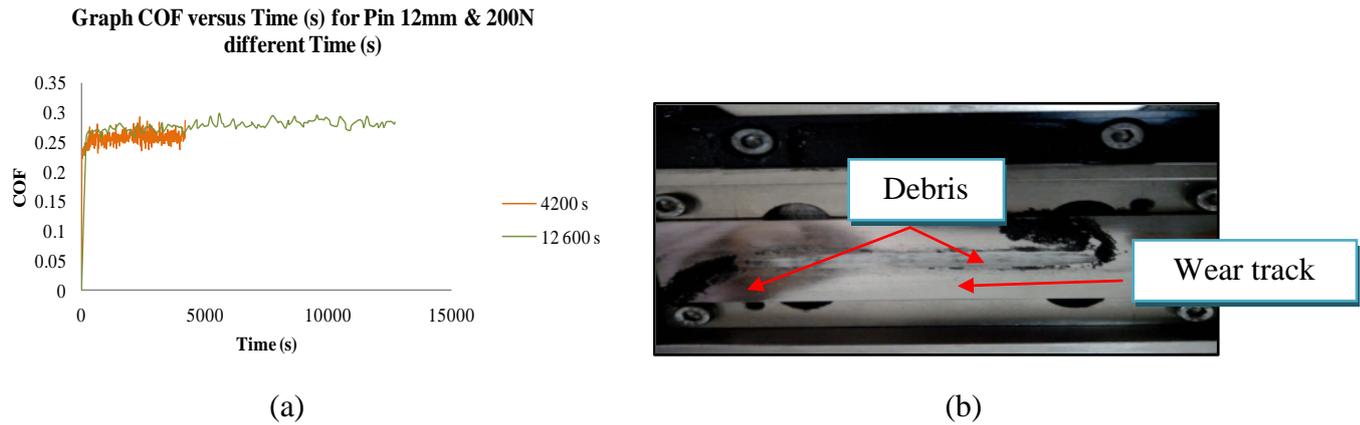
Fig. 2: (a) Evolution of COF of different duration of cycles, (b) debris after testing

3.2 Wear scar details

The result from the profilometer was used to determine the wear depth and length of the worn surface. Fig. 3 shows the plan view of some of the wear scar for the 12600 s duration of cycles. The width and depth of worn surface were measured from point *A* to point *B*. There are black spots detected on wear sliding track. The depth of the worn surface 375.323 µm that measured from the "U"-shaped (scar with single valley) at the higher of peak of the profilometer graph until the lower part of 'U'- shaped shows in Fig. 3 Contact surface in dry and lubricated produced the different scars shaped in reciprocation sliding wear test [11].

Fig. 3: Wear track profile for sliding until 12600 s (a) the plan view of the wear scar (b) The profilometry of the wear scar width and depth at middle track

Fig. 4 a) shows the bar chart of total weight loss, for different duration of cycles. The higher the duration of cycles, shows the higher total weight loss (g). Fig. 4 shows the amount of total weight loss over the duration of sliding for 12600 s is 134.256 x 10^{-6} g doubled amount of 4200 s case with 65.714 x 10^{-6} g. Based on Archard wear equation is given by:

$$\qquad (1)$$

where V is total wear volume, S is sliding distance, K is wear coefficient, P is normal load and H is hardness of the material. Wear coefficient, K can be defined by following equation:

$$— \qquad\qquad (2)$$

$$— \qquad\qquad (3)$$

Where m is mass of total weight loss and   is density of material. By letting Equation (3) into Equation (2), assume the normal load, P, density,   , hardness, H are constant and 1 second sliding distance, S is equal to 20 mm. The wear coefficient, K for the 4200 s and 12600 s duration of cycles are 0.3286×10^{-5} and 0.6712×10^{-5} respectively.

The wear area for the 4200 s and 12600 s duration of cycles are 0.00052 mm^2 and 169.2 mm^2. Based on the wear rate over wear area, the 4200 s is 0.126 g/mm^2 is higher than 12600 s where is is only 0.7935×10^{-6} g/mm^2. It shows that at 4200 s the amount of weight loss per sliding distance is higher than 12600 s.
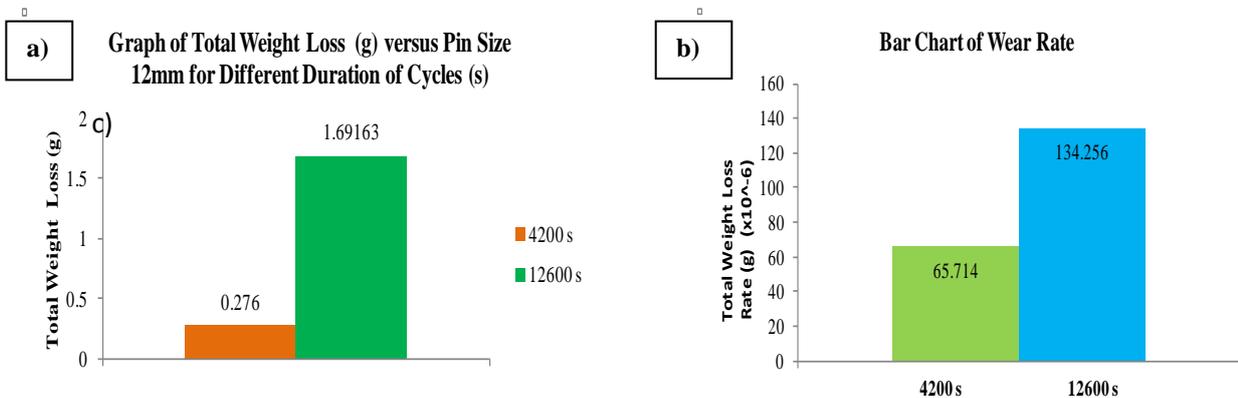

Fig. 4: a) bar chart of total weight loss (g) versus pin size 12 mm for different duration of cycles b) Bar chart of total weight loss (g) over the duration of cycles

Fig. 5 shows the black spot area on the wear scar for 4200 s duration of cycles. The same figures of black spot also determine at 12600 s duration of cycles. The black spot is figuring out mostly at the edge of the wear track specimen and also a few on the sliding wear track. The black spot also have mention as collected wear debris on the top layer surface that mostly accumulated at the edge and a few at worn track of the test at different sliding loads [12]. Fig. 6 shows the hardness on three regions at unworn, worn and black spot of the wear track. The results show the hardness is increasing from unworn, worn, and the black spot. There is no significant difference in the hardness values of Ti-6Al-4V for sliding duration between 4200 s and 12600 s. This confirms reproducibility the wear mechanism for this two different duration of cycles are same [13].
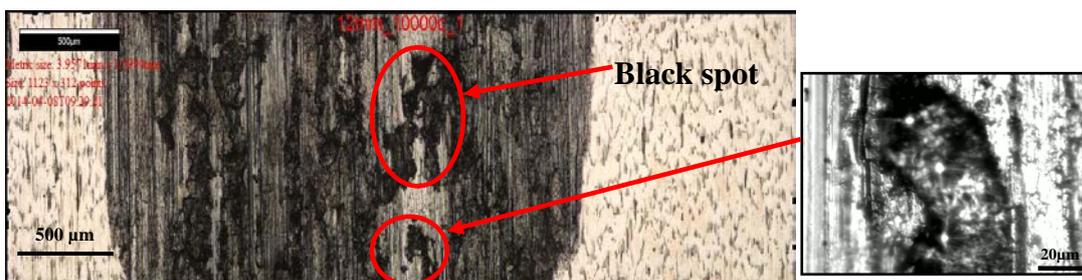

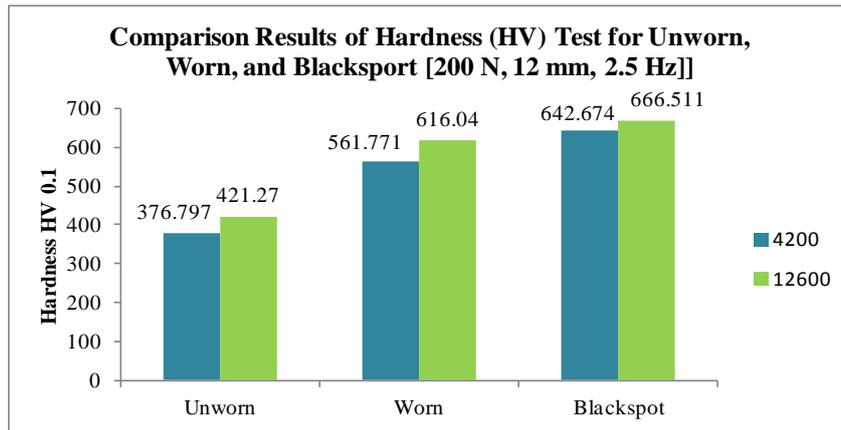Fig 5: Black spot area of hardness test for 4200 s duration of cycles

Fig. 6: Results of comparison of hardness (HV) for unworn, worn and black spot
(200 N, 12 mm, 2.5 Hz) for different duration of cycles

Based on the wear profilometry results in Fig. 3, the wear depth was calculated and the graph of wear depth against duration of cycles was illustrated in Fig. 7. The data for the low cycles case is taken from another researcher [14]. Due to peak contact pressure at initial cycles the progression of scar length developed high rate of wear and it decreases when the shear stresses are distributed over the large contact surfaces [15]. Therefore the wear rate started to stabilize with increasing duration of cycles.
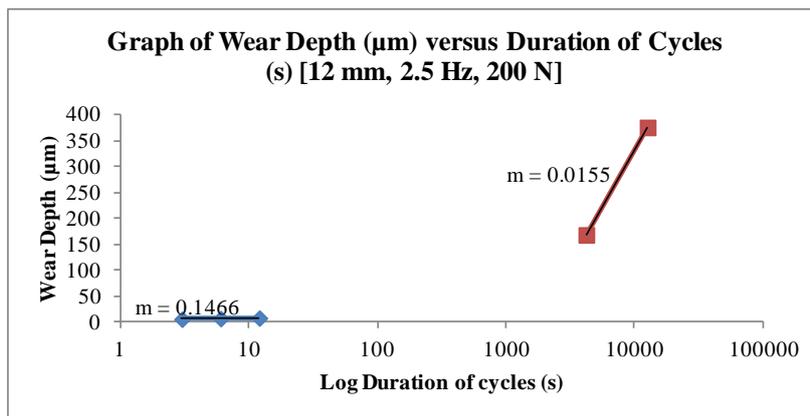

Fig. 7: Graph of combination low and high cycles wear depth(µm) versus log duration of cycles (N)
(12 mm, 2.5 Hz, 200 N)

5. Conclusion

Reciprocating sliding wear test between pin-on-flat Ti-6Al-4V/Ti-6Al-4V in dry conditions for constant normal load 200 N, speed of motor 100 RPM and variable duration of cycles 4200 s and 12600 s has been conducted. The average of coefficient of friction for the three testing shows the average of 0.265. This COF rate is stable start from 5 s until the end of testing. The wear rate starts to stabilise with increasing duration of cycles by seeing the value of weight loss over the duration of the cycle. The black spot which figures at the edge of wear track as known as collected wear adhesion debris shows the high value of hardness. The mechanism of wear can assume similar because there is no significant difference in hardness value at the unworn, worn, and black spot areas for 4200 s and 12600 s tests.

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