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"Wear Behaviour of Titanium Alloys When Subjected to Different Speed and Load Levels"

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Abstract*: *Titanium and Titanium alloys are widely used for aircraft as a material having light weight, high strength and corrosion resistance. The titanium and its alloys are compatible with carbon fibre reinforced plastic components with respect to corrosion and thermal behaviour.

Response of Titanium grade 2 and grade 12 at different speed during sliding is to be studied. The literature survey shows inadequate studies on wear response of these alloys.

Experiments using pin on disc test rigs were conducted. Speed level of 500rpm, 1000rpm, and 1500 rpm were used. The sliding was found to be sensitive to sliding speed. As speed increases from 500 rpm to 1000 rpm the coefficient of friction increased. At speed of 1500 rpm two steady phase of sliding identified. In one of the steady phase the coefficient of friction was found to be more than the coefficient of friction at 1000 rpm. Where in another steady phase of sliding the coefficient of friction was found to be comparable or less then the coefficient of friction at 1000 rpm.

Keywords* : *Wear, Speed, Friction, Coefficient of friction.

I. INTRODUCTION

Titanium and its alloys are exceptionally used in aerospace, because of their special features being light weight and more tough. Titanium alloys find broad use in turbine blades of aero engine. These aero engines are being demanded to run at high rate as possible so that flight timings are minimized. The special demand for motor to run at high speed also brings search for materials which could accomplish the desired requirement.

Ikuhiro Inagaki et al, brought out the extend of usage of Titanium and its alloys in their paper [1]. C Veiga et al in their review on properties and applications of Titanium alloy Emphasis the need of Titanium and its alloys in aerospace industries. They also brought about the importance of wear performance of Titanium alloys [2]. Katarzyna Sharman et al, studied the effect of mechanical working on microstructural and Mechanical properties of Titanium alloys. They found that mechanical working reached to grain refinement which improve tensile stress and hardness [3]. Kenneth G. Budinski attempted evaluating tribological behaviour of grade 2 commercial pure Titanium and age hardenable Ti6Al4V. He used dry sand rubber wheel abrader and pin on disc test rig. Their test results show poor abrasion resistanc [4]. Sergey Zherebtsov et al special tests like stress controlled bending fatigue, creep test apart from Standard mechanical property test were undertaken. Effect of temperature was also studied. The result showed that structure refinement leads to increase in strength and fatigue limit. Grain size of the alloy was also found to influence performance elevated temperature [5]. Mamoun Fellah et al, made attempt in evaluating the friction and wear behaviour of high strength Titanium alloys using ball on disc pin on disc test rigs. They identified ploughing and peeling of wear at low speed and plastic deformation on adhesive wear at high speed [6]. Danilo Fontes Ferreira et al, conducted experiments using pin on flat reciprocating tribo system with a facility to incorporate corrosion solution. They identified that the material loss was severe at higher load and speed [7]. Nickolay Yu. Sdobnyakov et al, simulated phase transfer mechanism in titanium nano alloy with cooling rate as a parameter. The simulation helped in identifying the specific features of structure formation [8]. Wit Grzesik et al, conducted experiment using pin on disc test rig for evaluating tribological behaviour of PUD-TiAlN coated carbide inserts and dual phased Titanium alloy tribo system. They identified both adhesive and severe abrasive wear phenomenon [9]. S Anandan et al, studies have been conducted in evaluating wear behaviour of titanium alloys using pin on disc test Rig. The results showed superior wear behaviour of Titanium [10]. Nadeem Pasha K and Dr. S Ranganatha studied the sliding response of grade 5 Titanium alloy using pin on disc test rig. The results indicated that coefficient of friction was sensitive to speed of sliding [11].

II. EXPERIMENTAL DETAILS

Two Titanium alloys (Grade 2 and Grade12) were taken in the form of a rectangular piece and the standard pin specimen is prepared as per ASTM Standards. Pin Specimens were prepared by wire EDM cutting process for the dimensions of 30 mm length and 8mm diameter. The pin specimen prepared by wire EDM cutting process, Pin specimen and the standard dimension of the pin is shown in Fig 1 and 2 respectively.

Fig. 1: Titanium Pins specimen prepared from EDM process.

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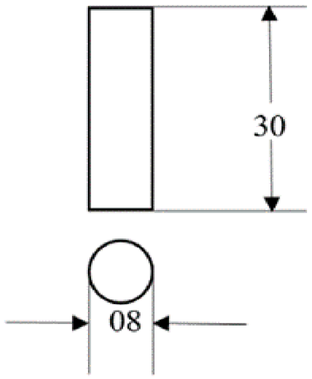


Fig.2: Dimensions of the pin used in mm.

Pin specimens were tested on pin on disc wear testing machine. Pin on disc wear testing machine has disc diameter of total 160mm, there are variety of holders designed for different size and shape of pins. The holder used in the present experiment can holds a pin of 8mm in diameter and 30mm in height. The test rig has a display device which displays amount of wear, friction, speed, temperature and time. The data like wear, frictional force, co-efficient of friction were recorded in a personal computer. The software for recording data is WINDUCOM. The WINDUCOM software was supplied by pin-on-disk test rig manufacturer. The test details like load, time and speed of experiments are given in Table I.

Table I: Different parameters used for experiments.

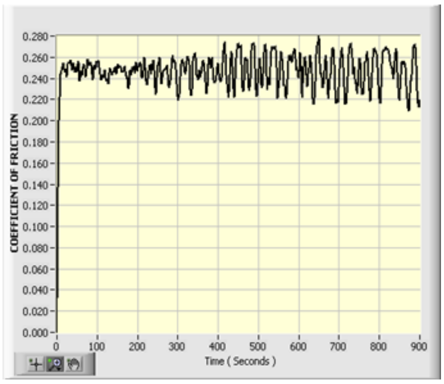
Sl No.	Titanium alloy	Load in Newton	Time in seconds	Speed in rpm
1.	Grade 2	30	900	500
2.	Grade 2	30	900	1000
3.	Grade 2	30	900	1500
4.	Grade 12	30	900	500
5.	Grade 12	30	900	1000
6.	Grade 12	30	900	1500

III. RESULTS AND DISCUSSIONS

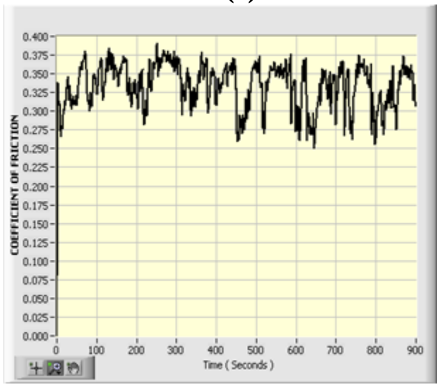
Two different grades of titanium alloys it is Grade2 and Grade12 pins were slid against En31 hardened steel disc using pin on disc test rig equipment according to ASTM standard.

Grade 2 (99.2% pure Ti)

Experiments were conducted by sliding titanium grade 2 pin on En31 steel disc. The sliding was conducted for a period of 15 minutes. The normal load was 3 kg. The speed of the disc were 500 rpm 1000 rpm and 1500 rpm. The frictional force measured and recorded on personal computer. The measured frictional force was used to estimate the coefficient of friction. Typical plots of dependency of coefficient of friction with respect to sliding time are shown in Fig. 3a, 3b and 3c.



(a)



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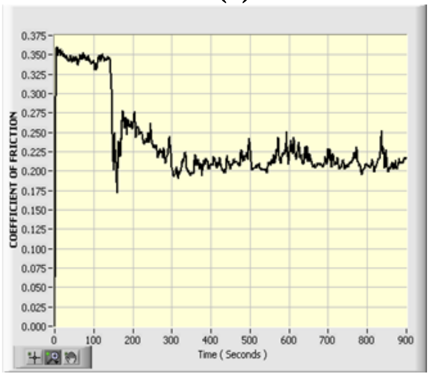


(c)

Fig.3: Dependency of coefficient of friction with respect to sliding time for different speeds (a) 500rpm; (b) 1000rpm; (c) 1500rpm for grade 2 Titanium pin.

Fig.3a shows the dependency of coefficient of friction with respect to sliding time for a sliding speed of 500 rpm and normal load 3kg. The coefficient of friction increased to approximately about 0.25 within 10 to 15 seconds. The fluctuation of coefficient of friction from sliding time of approximately from 15 seconds to 200 seconds was found to be less when compared to fluctuation of coefficient of friction after 200 seconds. The fluctuation of coefficient of friction after 200 seconds and until completion of the experiment was found to be consistent.

Fig. 3b show the dependency of coefficient of friction with respect to sliding time for a sliding speed of 1000 rpm and normal load 3 kg. The coefficient of friction increased to approximately 0.325 within 5 to 10 seconds from the start of the experiment. The coefficient of friction after this initial sliding remain steady over a mean value of approximately 0.35.

The coefficient of friction during this period was found to be fluctuate over the average value of coefficient of friction and this fluctuation was found to be consistent during the period from 10 seconds to completion of the experiment.

Fig. 3c show the dependency of coefficient of friction with respect to sliding time for a sliding speed of 1500 rpm and normal load 3 kg. The coefficient of friction was found to be approximately 0.35 after a small fraction of time it is about 5 seconds from the beginning of the experiment. The coefficient of friction was found to be approximately 0.35 from 5 seconds to approximately 150 seconds. The coefficient of friction was found to be decrease from approximately 0.25 at 150 seconds to 0.21 at 300 seconds. The coefficient of friction after 300 seconds until completion of experiments it is 900 seconds was found to be stabilized with a value of approximately 0.21.

The sliding behavior at sliding speed of 1500 RPM was found to be dependent on history of the sliding time. Two distinct steady state of sliding were observed during entire regime of sliding. The first regime is named as Phase 1 and this phase 1 existed in the initial stage of sliding with larger magnitude of coefficient of friction. After some initial state of sliding the second regime of steady state of sliding was observed and this regime is called phase 2 sliding. During the second phase of steady sliding the magnitude of friction was found to be smaller in magnitude when compared to magnitude of coefficient of friction in Phase 1.

This type of two phases of steady sliding was not observed at sliding speed of 500 rpm and 1000 rpm. The average value of coefficient of sliding were estimated from the above figure 3a, 3b and 3c these average coefficient of friction are tabulated in table II.

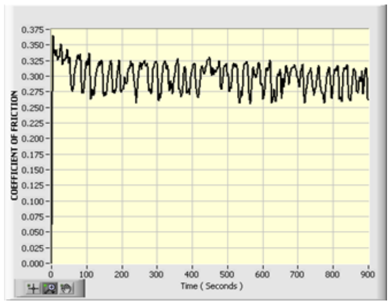
Table II: Average co-efficient of friction for different speeds on grade 2 Titanium alloy.

	500 rpm	1000 rpm	1500 rpm (Phase I)	1500 rpm (Phase II)
Average Coefficient of friction	0.24	0.33	0.35	0.21

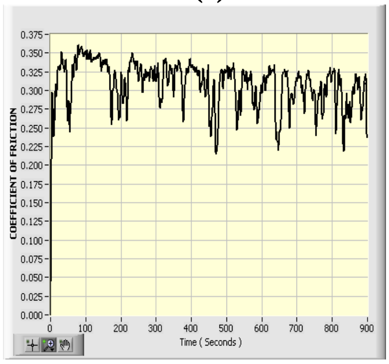
The average coefficient of friction was found to be 0.24 at 500 rpm 0.33 1000 rpm. The coefficient of friction at 1500 RPM exhibited the steady phase of sliding with an average value of 0.35 in Phase I and 0.21 in phase II. The average coefficient of friction was found to increase with increase in sliding speed at 500 rpm, 1000 rpm and phase I of 1500 rpm. Whereas the average coefficient of friction was found to increase from 500 rpm to 1000 rpm and decrease during Phase II of 1500 rpm.

Grade 12 (Ti 0.3Mo 0.8i):

Experiments were conducted by sliding titanium grade 12 pin on En31 steel disc. The sliding was conducted for a period of 15 minutes. The normal load was 3 kg. The speed of the disc were 500 rpm, 1000 rpm and 1500 rpm. The frictional force measured and recorded on personal computer. The measured frictional force was used to estimate the coefficient of friction. Typical plots of dependency of coefficient of friction with respect to sliding time are shown in Fig 4a, 4b and 4c.



(a)



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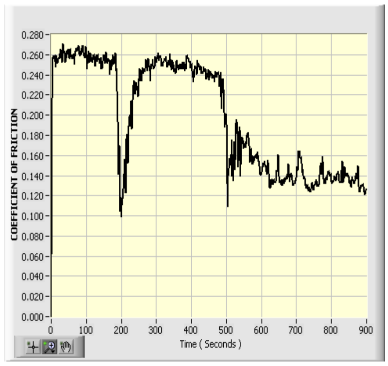

(c)

Fig.4: Dependency of coefficient of friction with respect to sliding time for different speeds (a) 500rpm; (b) 1000rpm; (c) 1500rpm for grade 12 Titanium pin.

Fig. 4a shows the dependency of coefficient of friction with respect to sliding time for a sliding speed of 500 rpm and normal load 3kg. The coefficient of friction increased to approximately about 0.36 within 10 to 15 seconds. The fluctuation of coefficient of friction after 200 seconds and until completion of the experiment was found to be consistent approximately at a value of 0.29 through the experiment except at the initial time of 10-15 second.

Fig. 4b show the dependency of coefficient of friction with respect to sliding time for a sliding speed of 1000 rpm and normal load 3 kg. The coefficient of friction increased to approximately 0.27 within 5 to 10 seconds from the start of the experiment. The coefficient of friction after this initial sliding remain steady over a mean value of approximately 0.30. The coefficient of friction during this period was found to be fluctuate over the average value of coefficient of friction and this fluctuation was found to be consistent during the period from 10 seconds to completion of the experiment.

Fig. 4c shows the dependency of coefficient of friction with respect to sliding time for a sliding speed of 1500 rpm and normal load 3 kg. The coefficient of friction was found to increase to approximate value of 0.26 after a laps of approximately 5 seconds after start of experiment. The coefficient of friction was found to be study after 5 seconds of experiment and up to approximately 500 seconds of experiment except a deviation for a small interval of time between approximate 200 seconds and 210 seconds. During this small interval of 200 and 210 seconds the magnitude of coefficient of friction dropped from 0.26 to 0.1 and again increased to approximate value of 0.26.

The sliding behavior at sliding speed of 1500 RPM was found to be dependent on history of the sliding time. Two distinct steady state of sliding were observed during entire regime of sliding. The first regime is named as Phase 1 and this phase 1 existed in the initial stage of sliding with smaller magnitude of coefficient of friction. After some initial state of sliding the second regime of steady state of sliding was observed and this regime is called phase 2 sliding. During the second phase of steady sliding the magnitude of friction was found to be very smaller in magnitude when compared to magnitude of coefficient of friction in Phase 1.

This type of two phases of steady sliding was not observed at sliding speed of 500 rpm and 1000 rpm. The average value of coefficient of sliding were estimated from the above Fig 4a, 4b and 4c these average coefficient of friction is tabulated in table III.

Table III Average co-efficient of friction for different speeds on grade 12 Titanium alloy.

	500 rpm	1000 rpm	1500 rpm (Phase I)	1500 rpm (Phase II)
Average Coefficient of friction	0.29	0.30	0.26	0.16

The dependency of coefficient of friction and sliding speed tabulated in table II and table III are plotted for titanium grade 2 and grade12 alloys and shown in Fig 5.

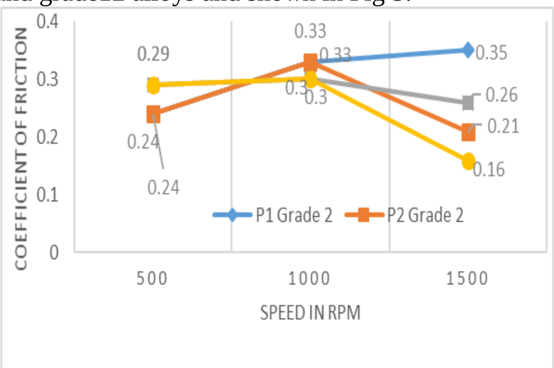

Fig.5: Average co-efficient of friction for different speeds on grade 2 and grade 12 Titanium alloy.

The two distinct phases of sliding are observed for both grade 2 and grade 12 Titanium alloys. The dependency of coefficient of friction in case of Grade 2 alloy is increase in magnitude of coefficient of friction at speed 500 rpm, 1000 rpm and Phase 1 of 1500 rpm. where as in phase 2 at 1500 rpm the magnitude of coefficient of friction is smaller when compare to magnitude of coefficient of friction at 500 and 1000 rpm. The dependency of coefficient of friction in case of grade 12 Titanium alloy also showed two distinct phases during sliding speed of 1500 rpm. The coefficient of friction for the two distinct phases of sliding at 1500 rpm are found to be smaller when compared to average coefficient of friction at speed 500 and 1000 rpm.

IV. CONCLUSION

1. Coefficient of friction was found to be dependent on load.
2. The coefficient of friction was also found to be dependent on speed.
3. Irrespective of type of Titanium alloy, two distinct steady phase of sliding were observed at sliding speed of 1500 rpm.
4. The grade 2 shows that the coefficient of friction increased as speed increases from 500 rpm, 1000 rpm and first phase of sliding 1500 rpm.
5. Further the grade 2 showed that a decrease in coefficient of friction during second phase of sliding at a speed of 1500 rpm.
6. The grade 12 show an increase in coefficient of friction when speed changes from 500 rpm to 1000 rpm, this alloy also exhibit two phases of steady sliding at speed 1500 rpm where in the coefficient of friction in both steady phase of sliding found to be lower in magnitude when compared to coefficient of friction at 1000 rpm.

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