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Sliding Response of Grade 5 Titanium Alloy at Different Speed and Load Levels

Nadeem Pasha K, S. Ranganatha, Salim Sharieff

Abstract: ***Titanium grade 5 alloy is being very distinct because of light weight and higher strength. These alloys are extensively used in aerospace industries. Response of these Titanium alloys under different load level and speed level during contact is required to be studied. The literature survey indicates inadequate studies on effect of load and speed during relative motion.***

Experiments have been conducted using Pin-On-Disc test rig in laboratory to simulated field conditions. Two load levels of 1.5kg and 3kg and three speed levels of 500,1000 and 1500rpm were maintained during experiments. Pin surface have been studied under Scanning Electron Micrograph [SEM] for understanding wear behaviour.

The coefficient of friction was found to be more sensitive to the speed of sliding. At speed of 1500 rpm, irrespective of normal load, two distinct sliding phases, i.e., phase I and phase II have been observed as sliding progressed. Oxidation of wear debris, at lower speed and phase I of sliding takes place.

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

I. INTRODUCTION

Titanium and its alloys are extremely used in aerospace, because of their special features being light weight and more tough. Titanium alloys find extensive 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.

Titanium and its alloys are extensively used which bridges the material requirement in manufacturing of aerospace components. These titanium alloy components used in aerospace industries are subjected to both complicated loading and thermal exposure. These complicated environment demands technical information which is required in designing of components. The more specific requirement in design is involving the information on wear and thermal effects. The literature survey indicates inadequate studies on effect of load and speed during relative motion.

Anandan et al, evaluated the wear behaviour of titanium material. Experiment have been conducted using pin on disc test rig. They observed that quantum of wear was increased with both speed and normal load [1]. Chauhan and Kalidass studied the dry sliding wear of titanium (Grade5) alloy. Experiments were conducted using pin on disc test rig. They developed a model for predicting wear and found that model predicted value were comparable with experimental values [2]. Rahman et al, evaluated the machinability of titanium alloys. One of the important result which has a bearing on tribology was very steep gradient in cutting temperature with cutting speed, an indicative of poor thermal conductivity was found [3]. Zherebstov et al, studied the effect of plastic deformation on mechanical properties. They found that sub micro crystalline alloy compared to micro crystalline alloy was found to be having more strength above 400ºC elevated temperature [4]. Budinski studied the tribological properties of titanium alloys. The experiments using rubber wheel abrader according to ASTM G65 was conducted. The result showed that anodization and coating with dry film lubricant improved the tribological behaviour [5]. Fellah et al, studied the tribological behaviour of Ti-6Al-7Nb. Tests have been conducted by using oscillating friction and wear test. The results suggested that for better wear and friction performance the surface coating and heat treatment are required [6]. Miller et al, found, galling on bare titanium, was found to seize when sliding on itself or can be with other metal [7]. Rigney et al, identified severe plastic deformation in case of ductile material tribo system [8]. Molinari et al, Alam and Haseeb, Young et al studied sliding of titanium alloys at different level of sliding speed, load, hardened steel disk and vacuum condition [9][10][11]. Guleryuz and Cimenoglu studied the effect of surface modification technique on wear behaviour of titanium alloys [12]. Chen et al, studied the wear behaviour of titanium alloys in varying load and speed conditions [13]. Sahoo et al considered the micro structure effect on dry sliding behaviour of titanium alloy [14]. The high temperature galling characteristic of titanium alloy in absence and presence of surface treatment, was studied by Blau et al [15]. Salim et al, studied the effect of different coating materials and found that both coating materials and their thickness influence the sliding phenomenon [16].

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II. EXPERIMENTAL DETAILS

The wrought Titanium grade 5 of diameter 5mm was supplied by National Aeronautic Limited. The pin specimen of 5mm diameter and 30mm length were machined and the dimensions of pin specimen is shown in Fig.1.

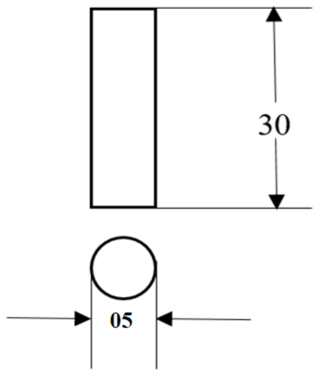


Fig.1: Dimensions of the pin used in mm.

Pin on disc test rig was used to conduct the experiment. The assembly of pin on disc test rig is shown in Fig.2.

Fig.2: Pin on disc test rig.

The disc was machined out of hardened En31 steel. The grade 5 Titanium pins were ultrasonically cleaned before conducting the experiment. The disc surface also cleaned by acetone. Experiments were conducted with different loads and speed levels. These load and speed levels and experimental time are given in Table I. Experiments have been systematically conducted. After each experiment titanium pins were carefully removed and studied for understanding wear mechanism in Scanning Electron Microscope.

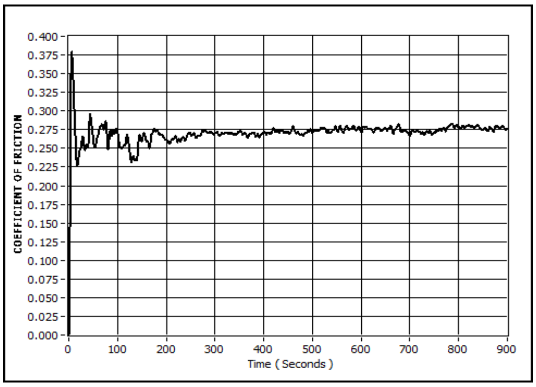
Experiments have been carried out by sliding Titanium (grade 5) pins on EN 31 hardened steel disc using pin on disc test rig. Normal loads and sliding velocities were varied. Table I shows the different test normal load and sliding speed.

Table I: Different parameters used for experiment.

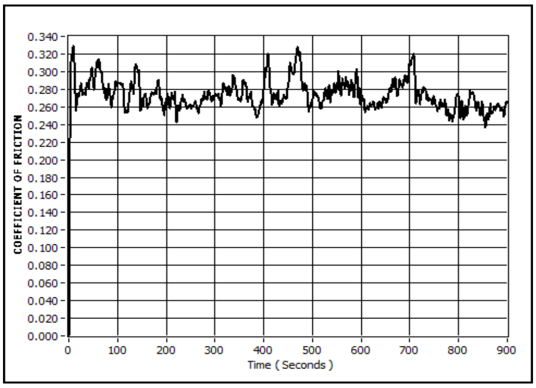
Sl No.	Load in kg	Speed in rpm
1.	1.5	500
2.	1.5	1000
3.	1.5	1500
4.	3	500
5.	3	1000
6.	3	1500

III. RESULTS AND DISCUSSIONS

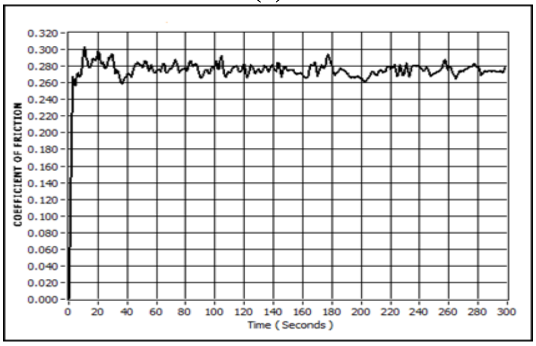
The monitored dependency of coefficient of friction on sliding speed of 500rpm and 1000rpm for a normal load of 1.5kg and 3 Kg are shown in Fig.3.



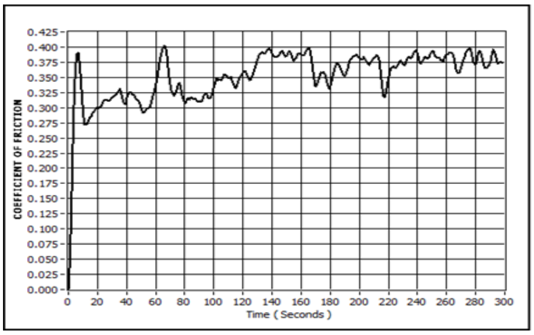
(a)



(b)



(c)



(d)

Fig.3: Dependency of coefficient of friction on sliding speed of 500rpm and 1000rpm for normal load of 1.5kg and 3kg.

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Plot (a) shown in Fig.3 shows the variation of coefficient of friction on sliding time for a speed of 500 rpm for a normal load of 1.5kg. The figure shows that the coefficient of friction fluctuates over an average value of approximately 0.26 from beginning over sliding time of 200 seconds. After 200 seconds, the coefficient of friction almost stabilized to a value of 0.275 until experiment was completed.

Plot(b) of Fig.3 shows the monitored coefficient of friction as time of sliding changed for a speed of 1000 rpm for normal load of 1.5 kg. The coefficient of friction appeared to be stabilized right from the beginning of the experiment and until experiment finished. The fluctuation in coefficient of friction was found to be an average value of coefficient of friction of 0.28. unlike in plot(a) the magnitude of fluctuation on mean value is larger.

Plot(c) of Fig.3 shows the monitored coefficient of friction on sliding time for a speed of 500 rpm for a normal load of 3kg. The coefficient of friction attained an approximate value of 0.28 within 3 seconds. The coefficient of friction stabilized at this value until experiment was completed.

Plot(d) of Fig.3 shows the monitored coefficient of friction and sliding time for a speed of 1000 rpm for a normal load of 3kg. The plot shows larger extent of variation in magnitude of coefficient of friction during sliding period. The coefficient of friction was found to be increased with a fluctuation from an average value of 0.32 to 0.38 up to sliding time of 120 seconds with a monotonic increase in the value of 0.375 during the starting of sliding. The average coefficient of friction was found to be stabilized after 120 seconds until closer of the experiment. During the stabilized duration of experiment, the coefficient of friction fluctuated above the mean value.

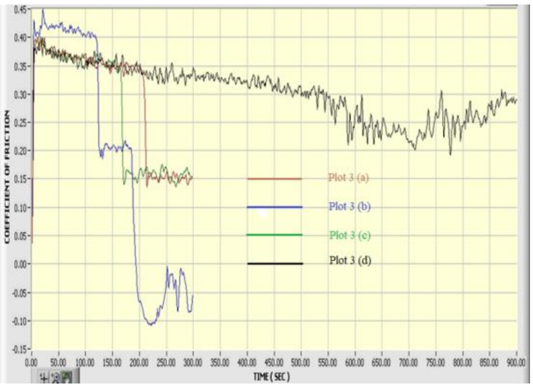

Fig.4: Dependency of coefficient of friction on sliding speed of 1500rpm for normal load of 1.5kg and 3kg.

The results at velocity of 1500 for a normal load of 3kg shows two distinct sliding behaviour as sliding time progressed. One of the distinct sliding behaviour was observed during initial time of sliding where the average coefficient of friction was 0.35. This initial time was found to be 0 to 125 second in few experiments and 0 to 225 seconds in other set of few experiments. This distinct phase observed during initial stage of sliding is named as phase I of sliding. The coefficient of friction during this phase was found to be of the order of 0.35. The coefficient of friction was found to be different after this initial period of sliding and up to the end of experiment. The sliding during this period of experiment is named as phase II. The coefficient of friction during the phase II was found to be of the order of 0.2 which is less compared to the value in phase I which is 0.35. Similar sliding behaviour was also found for normal load 1.5kg. At this normal load of 1.5 kg, phase I of sliding extended from beginning to approximately 600 seconds.

The average coefficient of friction from Fig.3 are estimated. The average coefficient of friction for two distinct phases of sliding are estimated from Fig.4. These estimated average values are tabulated in Table II.

Table II: Average coefficient of friction on sliding speed with normal load 1.5kg and 3kg.

Average Coefficient of friction	500 rpm	1000 rpm	1500 rpm (Phase I)	1500 rpm (Phase II)
Average Coefficient of friction for 1.5 kg	0.28	0.28	0.32	0.25
Average Coefficient of friction for 3kg	0.27	0.36	0.38	0.16
Total Average Coefficient of friction	0.28	0.32	0.35	0.20

The estimated average coefficient of friction for all loads at speed of 500rpm is 0.28. The average coefficient of friction for all loads at speed of 1000rpm is 0.32. The average coefficient of friction at speed of 1500 rpm in phase I is 0.35 similarly the average coefficient of friction at speed of 1500 rpm in phase II is 0.2.

The data in Table II which shows the dependency of the average coefficient of friction on normal loads of 1.5kg and 3kg are plotted and shown in Fig.5.

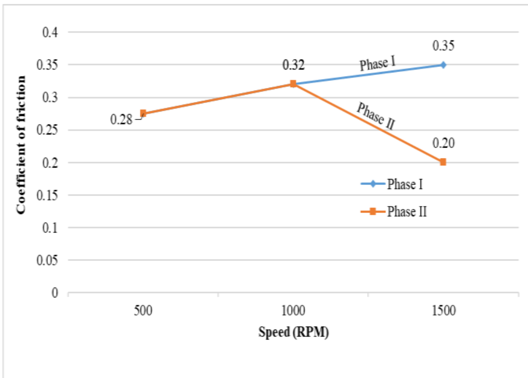

Fig.5: Dependency of the average coefficient of friction on normal load of 1.5kg and 3kg.

The Fig.5 shows dependency of coefficient of friction on speed. The coefficient of friction was found to increase monotonically with speed in phase I mode of sliding. The coefficient of friction during phase II of sliding was found to increase when speed changes from 500 to 1000rpm, with further increase in speed the coefficient of friction was found to be decreasing.

For identifying this dependency of coefficient of friction on normal load and speed, visual observation, scanning electron micrographic and Energy Dispersive Analysis X-Ray (EDAX) studies, have been carried out on worn pin surface.

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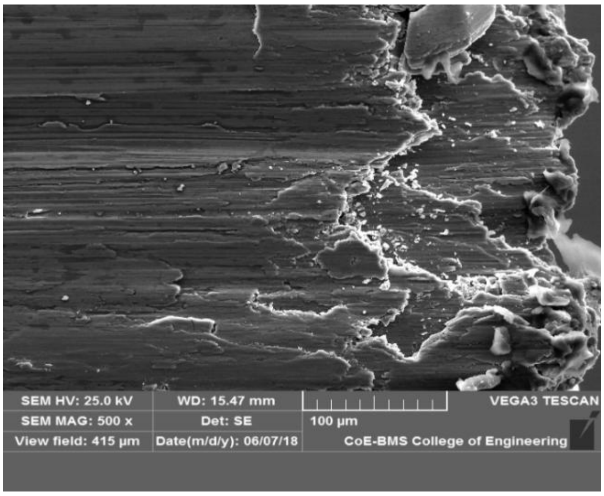
Visual Study: Visual observations have been carried out during sliding at all speeds and loads. At speed of 500, 1000 and first phase of 1500 rpm, it was observed that the wear debris got burnt with bright flashes. It was observed that during the second phase of sliding at speed 1500rpm, no such burning and flashing of wear debris occurred.

Scanning Electron Micrograph and EDAX study:

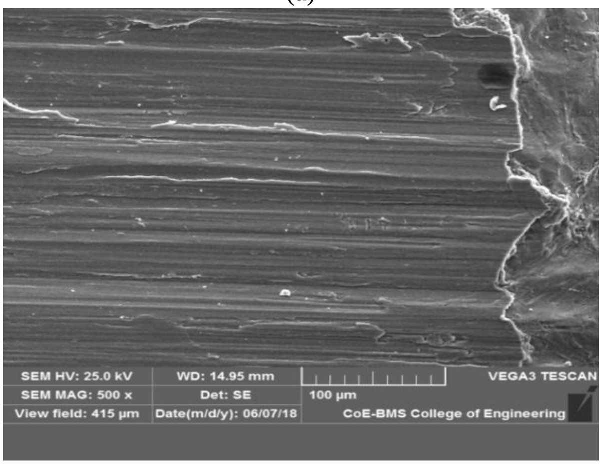
Scanning electron micrographic study and EDAX study for chemical composition has been carried out for identifying the possible mechanism which explains the dependency of coefficient of friction on sliding speed at different normal load.

Fig.6, Fig.7 and Fig.8 show the scanning electron micrograph for pin at different loads and speeds.

Fig.6 shows the Scanning electron micrograph at sliding speed of 500rpm and normal load 1.5kg and 3kg.



(a)

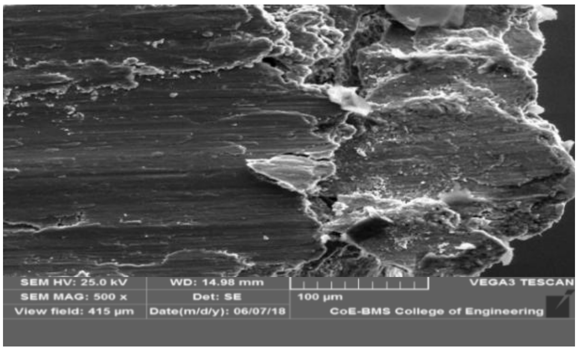


(b)

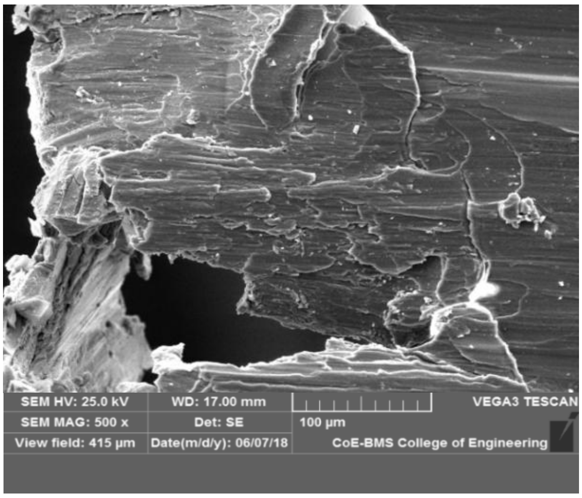
Fig.6: Scanning electron micrograph at normal speed of 500rpm for 1.5kg and 3kg normal load.

Micrograph (a) in Fig.6 shows the damaged pin surface at a normal load of 1.5kg. Micrographic morphology of damaged pin surface shows shallow grove without any features of adhesion phenomenon. Micrograph (b) in Fig.6 shows the pin surface at a load of 3kg. The features in micrograph (b) is almost similar to features of micrograph (a) without any adhesion features. These features of micrograph explain the observed average coefficient of friction being same for both normal loads of 1.5 kg and 3 kg at sliding speed of 500rpm.

Fig.7 shows the Scanning electron micrograph at sliding speed of 1000rpm for 1.5kg and 3kg normal load.



(a)

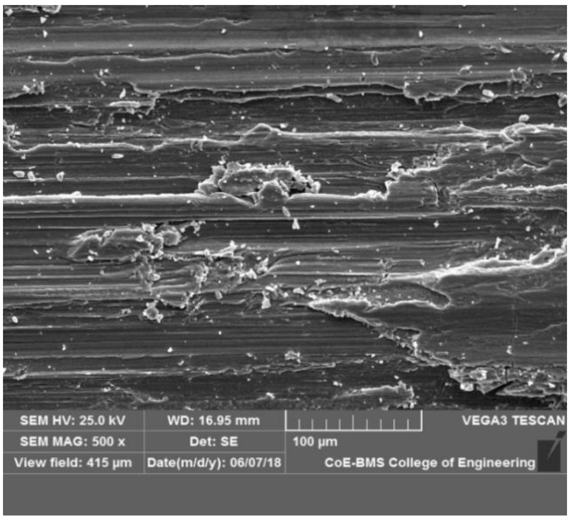


(b)

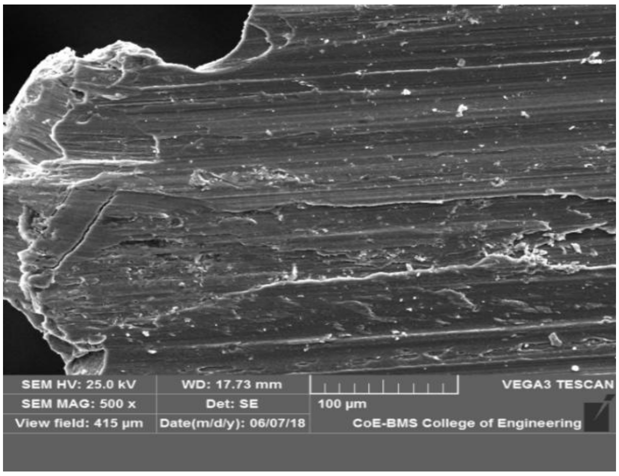
Fig.7: Scanning electron micrograph at normal speed of 1000rpm for 1.5kg and 3kg normal load.

Micrograph (a) in Fig.7 reveals the features which is similar to features found in Fig.6. Features in micrograph (b) of Fig.7 appears to be different from micrograph (a). Features reveals apart from abrasion a tensile mode of separation which is attributed to adhesion effect.

Micrograph in Fig.8 corresponds to normal load of 1.5kg and 3kg at a sliding speed of 1500rpm.



(a)



(b)

Fig.8: Scanning electron micrograph at normal speed of 1500rpm for 1.5kg and 3kg normal load.

Micrograph (a) of Fig.8 shows deep groves running parallel to the sliding direction across the length of the micrograph. These groves appeared to be narrow and ridges are broken at places. Patches of damage was observed on bottom right corner of the micrograph. The features reveals both adhesion and abrasion mode of sliding. Micrograph (b) of Fig.8 shows the features where in tensile mode of separation phenomenon accompanied with adhesion is appears to be much more dominant when compare to features observed in any other micrograph. Features of narrow groves without much cracks on the ridges are observed.

During experiment, bright burning and sparking of wear debris, were observed at velocities of 500 rpm and 1000 rpm irrespective of load i.e., 1.5kg and 3kg. At velocity of 1500rpm such burning of wear debris were observed during first phase of sliding, during the second phase of sliding at this velocity no sparking or burning was observed irrespective of normal load.

For finding out the reasons for the above observations, EDAX of pin surface was carried out. The content of different elements studied for different loads and velocity combination along with different trials for a given sample are tabulated in Table III. The weight percentage of oxygen, aluminium, titanium, vanadium and iron at different selected area on a pin surface, at different sliding speeds and different normal loads are tabulated in Table III.

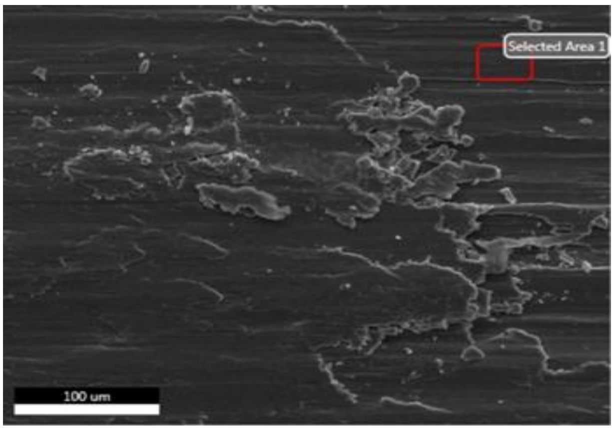
Table III: Weight percentage of Oxygen, Aluminium, Titanium, Vanadium and Iron at different selected areas of pin surface.

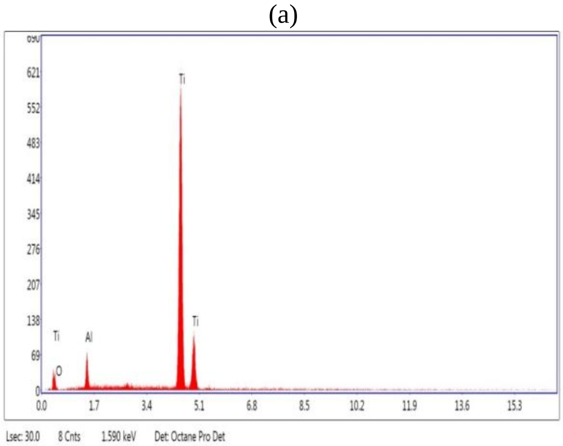
Element	500rpm -1.5kg	1000rpm-1.5kg	500rpm-3kg		1000rpm-3kg				1500rpm-3 kg
			Tr-1	Tr-2	Tr-1	Tr-2	Tr-3	Tr-4	
O	5.20	17.84	9.24	17.75	6.72	8.37	6.05	4.44	6.08
Al	5.45	6.50	5.67	4.82	6.53	3.36	6.09	6.76	5.69
Ti	83.24	70.77	79.63	57.18	81.01	80.87	82.01	82.30	81.75
V	4.87	4.20	4.18	------	4.70	5.28	4.39	5.07	5.08
Fe	1.24	0.69	1.29	20.24	1.04	2.12	1.44	1.43	1.40

The Table III indicates the weight percentage of oxygen as 6% by weight for the pin surface at 1500rpm during phase II of sliding suggesting no pickup of oxygen hence burning and sparks w ere not observed during this phase of sliding. Whereas at velocity of 500 and 1000 rpm the oxygen picked up was observed to be around 18% suggesting picking up of oxygen at these velocities hence bright burning of debris observed in this phase of sliding.

The typical EDAX image is shown in the Fig.9.

(a)





(b)

Fig.9: EDAX for selected area of pin.

IV. CONCLUSION

1. Coefficient of friction was found to be dependent on speed.
2. The coefficient of friction was also found to be dependent on normal load.

3. At speed of 1500 rpm, irrespective of normal load, two distinct sliding modes, i.e., phase I and phase II have been observed as sliding progressed.
4. Oxidation of wear debris, at lower speed and phase 1 of sliding takes place.

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