Wear Behavior of WC-Co Coating on TI6AL4V

Allu Harshitha
Department of Mechanical Engineering
Andhra University
Visakhapatnam, India

***Abstract*—Ti6Al4V alloys are widely used in chemical plants, automobile, aerospace industries and medical applications (bone, dental) because of its high specific strength. But, it has poor abrasive wear resistance due to high coefficient of friction and low thermal conductivity. Poor abrasive wear resistance results in the formation of wear debris on the surface of the alloy. In the present paper, detonation spray (DS) surface treatment method was used to Ti6Al4V to mitigate wear of the alloy. WC-Co Ceramic coatings of 450µm thickness were deposited on Ti6Al4V. Wear tests were performed on coated material to investigate different Tribological properties under dry sliding condition using pin on disc equipment. Process parameters such as sliding distance, velocity and load were considered in the present work. Taguchi method was used to know the optimum combination of process parameters and Signal to Noise ratio was applied to coefficient of friction finally confirmation tests were conducted for best SN ratio processes parameters. Confirmation tests have good agreement with the SN ratio processes parameters. In this work the effect of above surface treatment was studied on the wear behavior of Ti-6Al-4V alloy and an improvement in the wear resistance of the alloy is reported.**

Keywords— Titanium, Wear Behaviour,Detonation study,Alloy

I. INTRODUCTION

Titanium is a newcomer among the metals that have gained widespread industrial importance. Commercially pure titanium has acceptable mechanical properties and has been used for orthopedic and dental implants. Titanium is classified as a "Transition Metal" which are located in Groups 3 - 12 of the Periodic Table. An Element classified as a Transition Metals is ductile, malleable, and able to conduct electricity and heat. Titanium alloys are metals that contain a mixture of titanium and other chemical elements (such as aluminum, vanadium). For most applications titanium is alloyed with small amounts of aluminum and vanadium, typically 6% and 4% respectively, by weight. Such alloys have very high tensile strength and toughness (even at extreme temperatures).

Titanium has a good biocompatibility but it has a high coefficient of friction which results in poor abrasive wear resistance. The property of poor abrasive resistance is important in generating a wear debris.Inorder to treat Titanium as a Bio material it should prove its Mechanical properties, Bio compatibility, and High corrosion and wear resistance as the materials replaced the bone must have a similar bone modulus as studied by The bone modulus varies in the magnitude from 4 to 30 Gpa depending on the type of the bone and the direction of measurement (Lawrence, 1980) (Black and Hastings, 1998).implants with biomechanical incompatibility that leads to death of bone cells is called as ‘‘stress shielding effect” (Sumner et.al 1998),even the low wear and corrosion resistance of the implants in the body fluid results in the release of non-compatible metal ions by the implants into the body. The released ions are found to cause allergic and toxic reaction (Hallab et.al, 2005). The objective of the present investigation is to find the optimum combination of parameters for the wear rate and weight loss analysis of TI6AL4V by studying the dry sliding wear behavior of TI6AL4V.

II. METHODOLOGY

A. Tauguchi Methodology

Taguchi method is a scientifically disciplined mechanism for evaluating and implementing improvements in products, processes, materials, equipment, and facilities. These improvements are aimed at improving the desired characteristics and simultaneously reducing the number of defects by studying the key variables controlling the process and optimizing the procedures or design to yield the best results.

III. RESULTS AND DISCUSSION

A. Wear analysis of specimen 1

Below mentioned is the various results during the process such that figure 1 a) represents wear (in micrometers) versus time. Figure 1 b) represents the behavior of the metal during the process of how it shows the variation as time increases. We can note down in a tabular method the mean as the coefficient of friction. Figure 1 c) this graph shows us the variation of temperature in the specimen as the time increases which is constant after reaching a certain point. Figure 1 d) this graph represents the frictional force variations with regard to time.

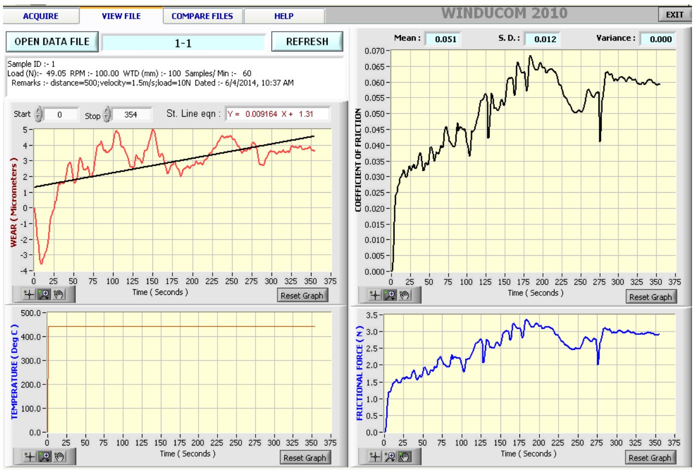


Fig. 1. Graphs showing values of coefficient of friction vs time at various conditions.

B. Wear analysis of specimen 7

Among all the nine specimens we have considered with a combination of process parameters, the conditions given for the specimen stands out to be the best with minimum wear. The conditions are such that Distance =1000m, Sliding Velocity=4.5m/sec, Load=10N.Below mentioned is the various results during the process such that figure 7 a) represents wear (in micrometers) versus time. Figure 7 b) represents the behavior of the metal during the process of how it shows the variation as time increases. We can note down in a tabular method the mean as the coefficient of friction. Figure 7 c) this graph shows us the variation of temperature in the specimen as the time increases which is constant after reaching a certain point. Figure 7 d) this graph represents the frictional force variations with regard to time.

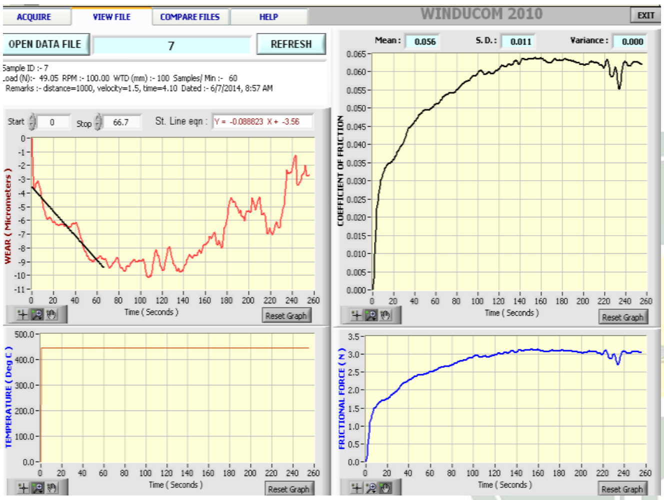


Fig. 2. Graphs showing values of coefficient of friction vs time at various conditions for specimen 7.

1) Calculated S/N ratio: Optimal levels of parameters for responses are estimated by S/N ratio analysis.

2) S/N Response table for coefficient of friction:

S/N Response table for µ			
Levels	**Distance**	**Velocity**	**Load**
1	29.3955	19.3467	25.3069
2	19.0362	19.6639	29.0927
3	14.7200	28.2654	12.9321
Delta	14.6755	8.9187	16.16063889
Rank	2	3	1

The above mentioned table is the mean responsible table for coefficient of friction. Among the process parameters Load is ranked 1, followed by Distance with rank 2 and Velocity at number 3.

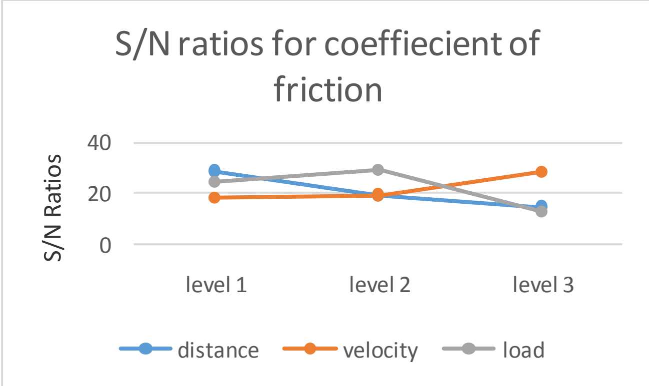


Fig. 3. Graph representing the S/N ratios for coefficient of friction at different levels.

Above results revealed that the increase in load and velocity will increase the wear. And the specific wear rate decreases with increase in distance and decrease in speed.

3) S/N ratio for weight loss: Weight loss values are analyzed using Taguchi S/N ratio analyzed by applying lower is better as quality character.

S.No	**Distance M**	**Velocity m/sec**	**Load N**	**Weight loss%**	**S/N ratios for weight loss%**
1	500	1.5	10	0.70	3.0980
2	1000	3	20	2.99	-9.5134
3	1500	4.5	30	0.91	0.8191
4	1500	3	10	0.33	9.1186
5	500	4.5	20	0.50	6.0205
6	1000	1.5	30	0.49	6.1960
7	1000	4.5	10	0.40	7.9588
8	1500	1.5	20	3.12	-9.8830
9	500	3	30	1.21	-1.6557

Mean responsible for Weight loss. Among the process parameters Velocity is ranked 1, followed by Distance with rank 2 and Load at number 3.We can also see the ranking of the each such that.

TABLE I. S/N RESPONSE TABLE FOR WEIGHT LOSS

Levels	**Distance**	**Velocity**	**Load**
1	2.4876	-0.1963	6.7251
2	1.5471	-0.6835	-4.4586
3	0.018	4.9328	1.7864
Delta	2.4696	4.2493	2.2665
Rank	2	1	3

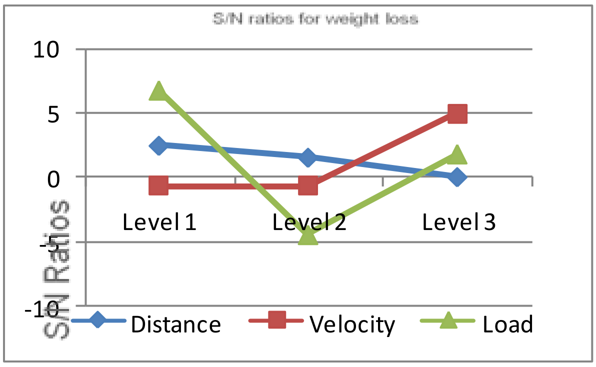


Fig. 4. S/N ratios for weight loss.

The above graph revealed that the increase in velocity and normal applied load will increase the weight loss. And decreases with increase in distance and decrease in load.

4) Characterisation of coating: WC-Co powder is deposited with an average particle size of 30µm as shown in Figure 1 WC-Co as 450µm thick deposited by the DS process as shown in Fig. 2.

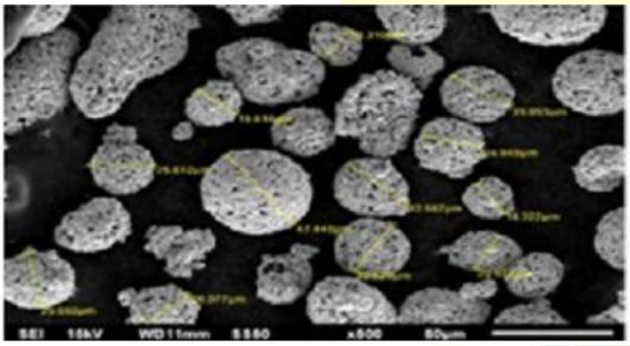


Fig. 5. SEM Microstructure of WC-Co coating on TI6AL4V.

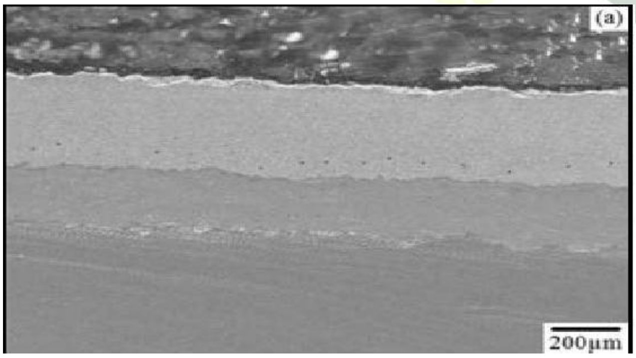
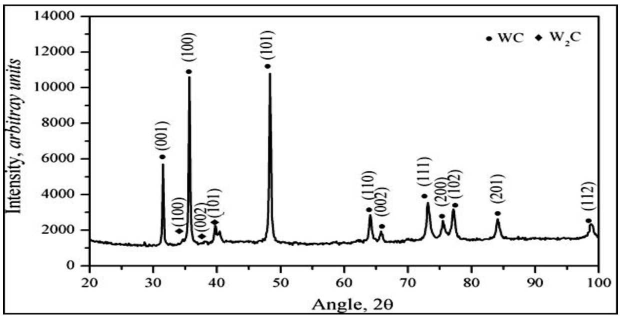


Fig. 6. SEM Cross Sectional Coating of 450 µm Thickness.

Microstructural characterization studies were conducted on WC-Co coated samples of TI6AL4V by using scanning electron microscope JSM-6610LV Scanning electron microscope (SEM) equipped with energy dispersive X- ray analyzer (EDX) is used to study the microstructure of the samples. X-ray diffraction patterns of the powders and coatings were taken using an Ultima IV X-ray diffract meter with CuKa radiation and Ni filter. The XRD analysis was carried out at a voltage of 40 kV and 30 mA current intensity.

The XRD pattern of the ceramic top coat is shown in Figure 3. The peaks corresponding to WC have been observed in the pattern.



5) Micro hardness Measurements: The micro hardness for different coating thickness is shown in Figure 5. It is observed that the micro hardness increases with the increase in coating thickness. The increase in micro hardness can be attributed to the decrease in the porosity as the coating thickness increases due to the dense coating.

TABLE II. MICRO HARDNESS VALUES

S.NO	Vickers hardness test
1	396.6
2	357.6
3	312.7
4	335.1
5	322.1

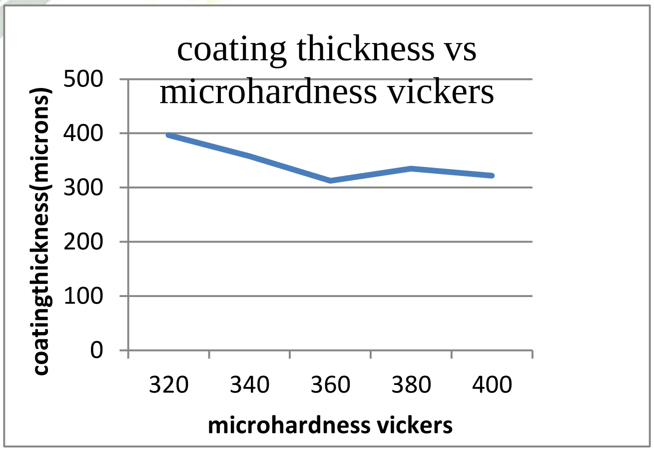


Fig. 7. Coating thickness versus micro hardness Vickers.

6) Wear track Analysis and optical analysis: A pin-on -disc wear testing (ASTM G99-04 standards) was performed to simulate sliding wear of the coatings. The Chrome Steel was used as the disc material Figure 5 shows the wear track morphologies of substrate and coated sample with ceramic thickness 450µm. Figure 5a shows that the substrate is subjected to a severe wear characterized by plastic deformation, shearing and abrasion. It can be seen that the surface of the substrate is severely deformed and scored which causes a significant roughening and formation of the grain-like wear debris. These indicate the typical adhesive wear process. In addition, the parallel grooves and scratches are observed in the wear track of the substrate. These kinds of grooves are the typical damages for plough wear mechanism, wear debris generated during wear, and this hard oxidized wear debris causes micro-abrasion. The coated sample shows less plastic deformation within the wear track (see Figure 5b). The wear track shows evidence of limited micro-cutting but a significant brittle fracture of the coating.

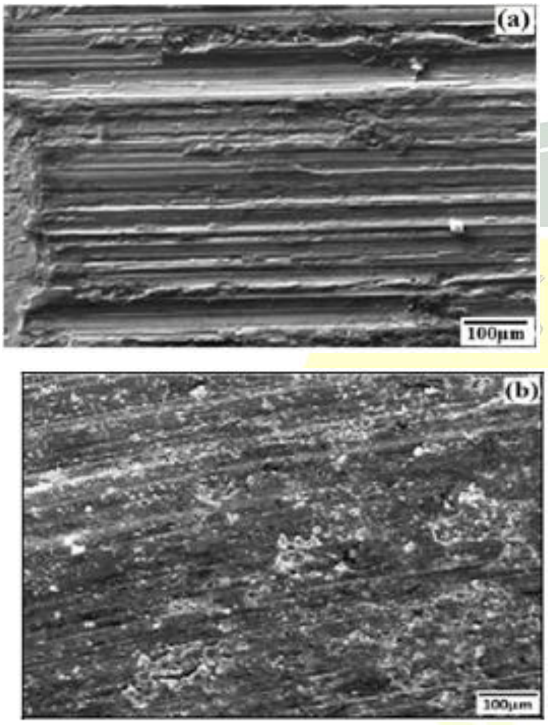
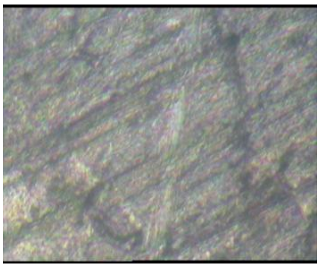
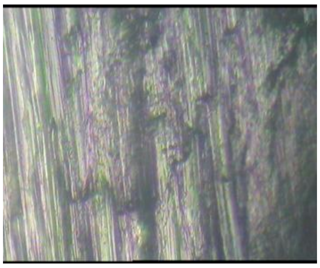


Fig. 8. SEM Worn Surfaces of (a) Substrate (b) Coated Specimen with Ceramic Thickness 450µm.

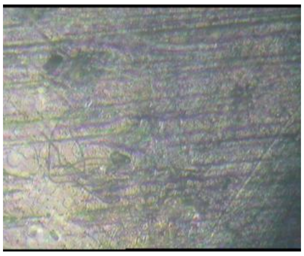
Optical micrographs of wear tracks on the after pin on disc tests for different process parameters at 100x are as follows.



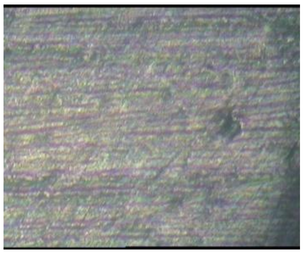
Specimen 1



Specimen 2



Specimen 3



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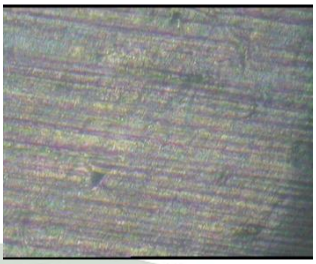
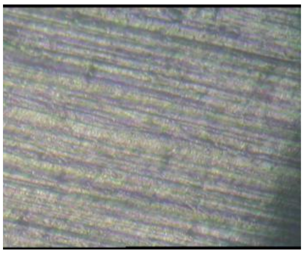
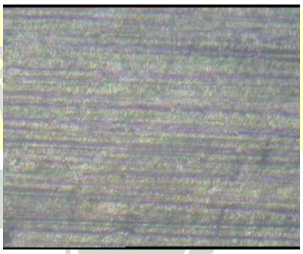


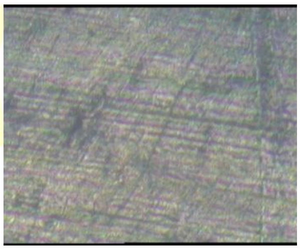
Specimen 5



Specimen 6



Specimen 7



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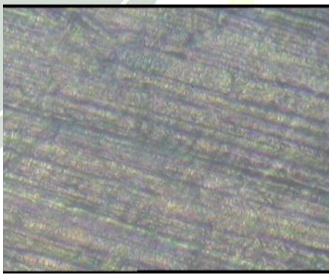

Specimen 9

Optical micrographs of wear tracks on the after pin on disc tests for different process parameters at 100x.

- Sliding distance=500m, Velocity=1.5m/sec, Load=10N
- Sliding distance=1000m, Velocity=3m/sec, Load=20N
- Sliding distance=1500m, Velocity=4.5m/sec, Load=30N
- Sliding distance=1500m, Velocity=3m/sec, Load=10N
- Sliding distance=500m, Velocity=4.5m/sec, Load=20N
- Sliding distance=1000m, Velocity=1.5m/sec, Load=30N

- Sliding distance=1000m, Velocity=4.5m/sec, Load=10N
- Sliding distance=1500m, Velocity=1.5m/sec, Load=20N
- Sliding distance=500m, Velocity=3m/sec, Load=30N.

The above tabulated figures are the wear tracks of the nine specimens, each at various combinations of process parameters. Among all of them, the best coefficient of friction is for the specimen 7 with figure g. And the optimum combination for weight loss is the specimen 6.

CONCLUSION

The Specific wear rate has been developed to investigate the tribiological behavior of titanium (Grade 5) alloy under dry sliding conditions against a steel disc by using response surface methodology. The effects of wear variables such as sliding speed, applied normal load and sliding distance have been evaluated. The following conclusions are conclusions are drawn based on the experimental investigations.

- The Specific wear rate increases with an increase in the normal applied load and speed decreases with an increase in the sliding distance and a decrease in the speed.
- The specific weight loss increases with an increase with an increase in the sliding velocity and normal applied load and decreases with an increases with an increase in the sliding distance and a decrease in the load.

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