CERAMIC COATING [TIO$_2$-ZRO$_2$] ON ALUMINIUM 6061T6 FOR ANTI WEAR PROPERTIES

Sachin Jadav N[1], Anil Kumar C[2]

[1]P.G. Student, Department of Mechanical Engineering, K S Institute of Technology, Bangalore, Karnataka, India
[2]Prof. & PG Co-ordinator, Department of Mechanical Engineering, K S Institute of Technology, Bangalore, Karnataka, India

Abstract

In this investigation, a ceramic coating of Titania (TiO_2) Zirconia (ZrO_2) and Titania-Zirconia (TiO_2+40%ZrO_2) with different coating thicknesses of 100µm, 150µm and 200µm are deposited on Al-6061T6 substrate using Atmospheric Plasma spraying technique. NiCrAl is used as a bond coat material to promote coating adhesion. Dry wear test was performed for a constant load of 10N, different sliding distance of 1000m, 2000m, and 3000m by using a Pin-on-Disc. The coating samples were subjected to abrasive wear test as per ASTMG99. From the results it was found that wear rate and coefficient of friction depend on various parameters such as microstructure, coating thickness, porosity, surface roughness and hardness. The mechanism of wear was also found that due to abrasion and once the bond coat is exposed to the disc, it loses material by adhesion. The results obtained from the above work showed that, the Zirconia coated specimens is having excellent wear resistance property when compared to Titania and Titania-Zirconia coating materials. The SEM of the worn surfaces of coated specimen shows better results than that of the Al-6061T6.

Keywords: *Ceramic coatings, Aluminium 6061T6, Titania (TiO2), Zirconia (ZrO2), Thermal Barrier Coating, Surface Roughness.*

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1. INTRODUCTION

Aluminium alloys is an important material for tribological applications due to its good capability to be strengthened by precipitation, low density, good corrosion resistance and high thermal and electrical conductivity improved are usually reinforced by Al2O3, Sic, SiO2, B, BN. Therefore, the investigation of tribological behaviour of aluminum based materials is becoming increasingly important. Aluminum is the most popular matrix for the metal matrix composites (MMCs). In the present investigation, aluminum alloy 6061 was used as the matrix material. Aluminum 6061T6 alloy has the highest strength and ductility of the aluminum alloys with excellent machinability and good bearing and wear properties.

Thermal spraying can provide thick coatings (approx. thickness range is 20 micrometers to several micrometers, depending on the process and feedstock), over a sizably voluminous area at high deposition rate as compared to other coating processes such as physical, electroplating and chemical vapor deposition. Coating materials available for thermal spray process include metals, ceramics, alloys, plastics and composites. They are fed in wire or powder form, heated to a molten or semi molten state and accelerated towards substrates in the form of micrometer-size particles. Plasma Spraying is one such technique that involves projection of selected powder particles into the area of high thermal density (Plasma gun), where they are melted, accelerated and directed on to the substrate surface. Coatings are formed by the immediate solidification of the molten droplets on the substrate surface of lower temperature where they form splats. Plasma sprayed Zirconia is used as a wear resistant coating applied to combustion system components such as valves, pistons, liners and piston fire decks in diesel engines [1-7]

2. EXPERIMENTAL WORK

Plasma Spraying. Al-606lT6 circular pins of diameter 8mm and length 30mm were selected as substrate material for coating. TiO_2 and ZrO_2 powders are used as coating materials and the mixture of both to form three different compositions shown in Table 1. The composition of the Al-6061T6 is given in Table 2. In this investigation NiCrAl bond coat of 10-20µm was deposited between coating and substrate for the purpose of best adhesion property and the top coat with 100µm, 150µm and 200µm thick deposited by plasma spray process [8] shown in Figure 1. The parameters of plasma spray process are listed in Table 3.

Table 1: Ceramic coating powders (wt %)

Composition	TiO_2	ZrO_2
1	100	-
2	-	100
3	60	40

Table 2: Chemical composition of Al-6061T6 alloy

Constituent	Percentage
Cu	0.226
Mg	0.809

Si	0.610
Fe	0.140
Mn	0.034
Ti	0.031
Zn	0.005
Cr	0.073
Al	Bal

Table 3: Parameters of Plasma spray process

Coating Parameters	
Gun	METCO 3MB
Primary gas flow rate (Argon, lpm)	80-90
Secondary gas flow rate (Hydrogen, lpm)	15-20
Carrier gas flow rate (Nitrogen, lpm)	37-40
Powder feed (grams/min)	40-45
Spray distance (mm)	100
Current (A)	500
Voltage (V)	60-70

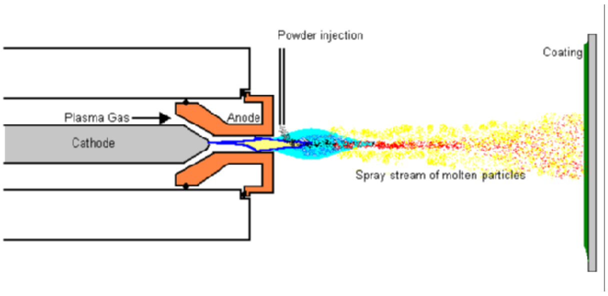

Fig 1: Plasma spray process

2.1 Characterization Of Coatings

Micro structural characterization and coating layers thickness of plasma sprayed on TiO_2, ZrO_2 and TiO_2+40%ZrO_2 coated samples were studied using a scanning electron microscope (SEM).

2.2 Micro-Hardness

Hardness measurement is done to find micro-hardness [9] of substrate and coated material. Micro-hardness test was performed on a cross section of coatings with a load of 250g and dwell period of 10 sec and average of three reading are tabulated in Table 5

2.3 Surface Roughness Measurements

Surface roughness was measured using a Talysurf instrument as shown in Figure 2. Before conducting the wear tests the surface roughness of pins were measured. The cut-off length was 0.8 mm, an average of five reading is reported in Table 4.

Table 4: Surface Roughness Values for uncoated and coated specimen

Coating Material	**Coating Thickness**	**Roughness Value R_a (µm)**	
		Before Wear Test	**After Wear Test**
Uncoated	-	12.71	2.78
TiO_2	100 µm	32.26	4.53
	150 µm	15.35	3.32
	200 µm	7.99	0.65
ZrO_2	100 µm	13.82	4.33
	150 µm	7.84	3.37
	200 µm	6.5	3.02
TiO_2 + 40%ZrO_2	100 µm	20.67	4.42
	150 µm	19.04	4.35
	200 µm	15.23	3.29

2.4 Wear Testing

The dry wear tests were carried out on coated specimens using Pin-on-Disc wear testing machine as shown in Figure3 according to ASTM G99-04 standards [10]. The cylindrical pins of 8mm diameter and 30mm length coated with TiO_2, ZrO_2 and TiO_2+40%ZrO_2 oxides of different coating thickness were used as test material. Hardened ground steel was used as disk (counter face material). The three wear tests were performed on each sample under a load of 10N for a sliding speed of 265rpm, 530rpm and 795rpm, over a sliding distance of 1000m, 2000m and 3000m respectively. Weight losses of the specimens were quantified by utilizing an electronic weighing balance. The specific structural feature of wear scars was observed by SEM in order to identify the microstructural comportment and wear mechanism for both uncoated and coated samples.

Fig 2: Talysurf Instrument

Fig 3: Wear testing machine

3. EXPERIMENTAL RESULTS

3.1 Characterization of Coatings

Figure 4 and 5 shows the SEM images of coating powder samples at 200x magnification and the SEM images of the coated specimens before wear test on Al-6061T6 substrate are shown in Figure 6,7 and 8 that is TiO2, ZrO2 and TiO2+40%ZrO2 with a little porosity present on surface of the samples.

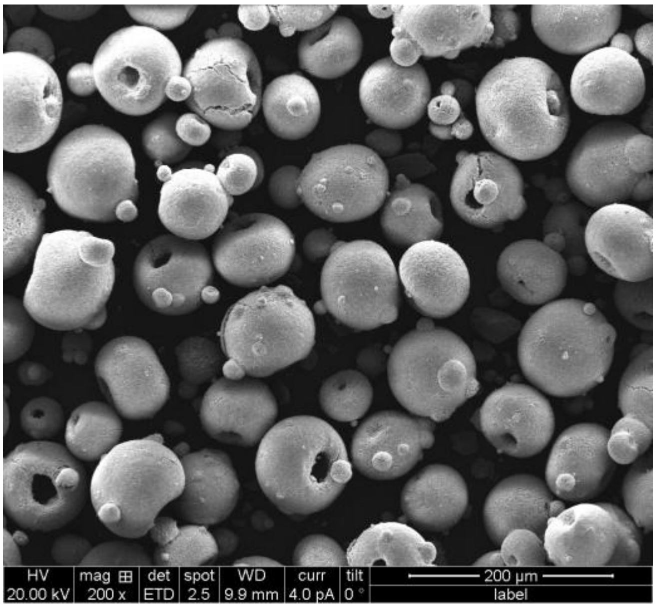

Fig 4: SEM image of TiO_2 at 200x magnification

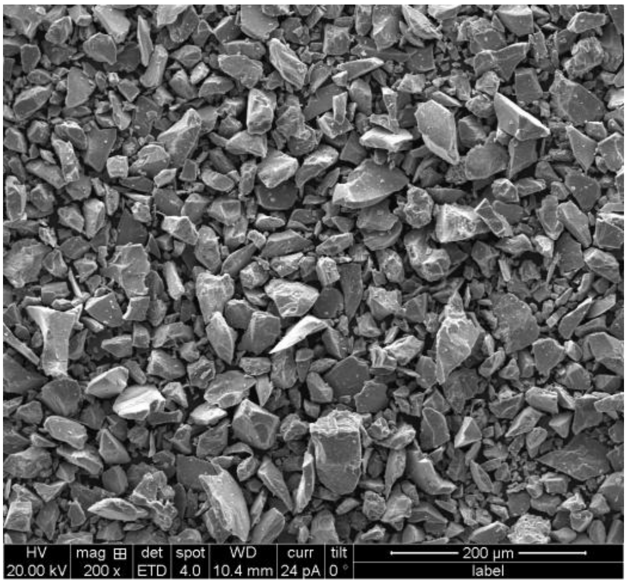

Fig 5: SEM image of ZrO_2 at 200x magnification

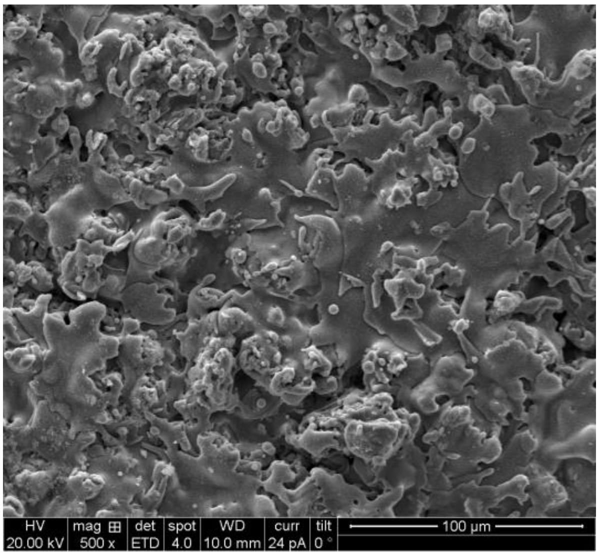

Fig 6: SEM image of TiO_2 coated specimen

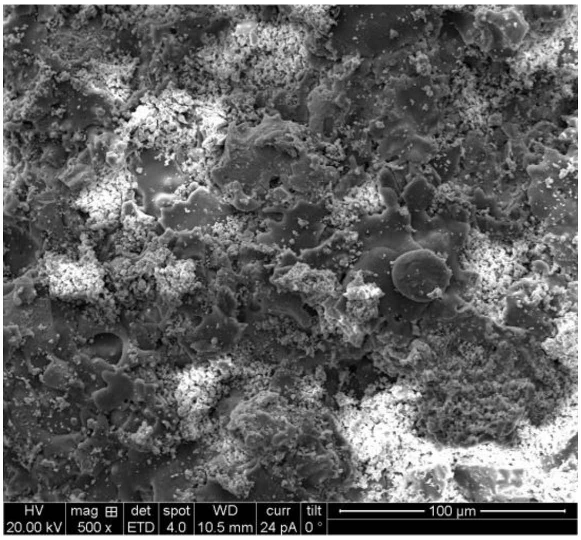

Fig 7: SEM image of ZrO_2 coated specimen

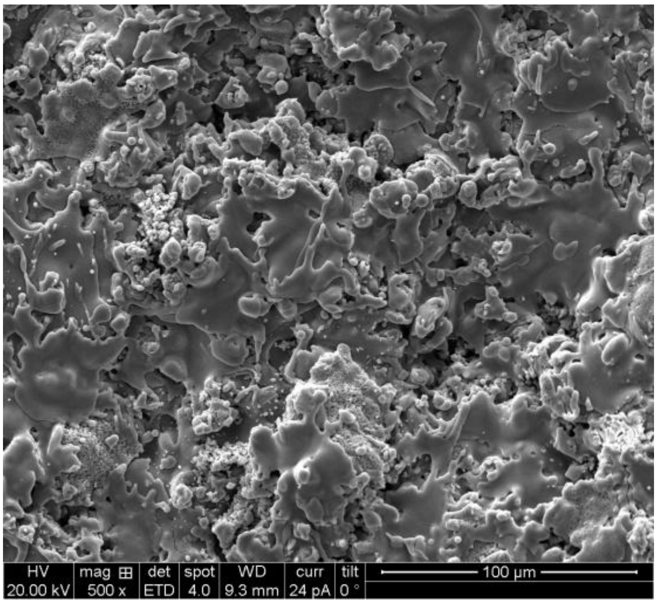

Fig 8: SEM image of TiO_2+40%ZrO_2 coated specimen

3.2 Surface Roughness Measurement

The figure 9 shows the values recorded both for coated and uncoated specimens before wear test indicating higher Ra values in comparison with the specimen surface after wear test. Observations for coated specimens show that coating material particles along with the bond surface have created a rough surface area. After the conduction of wear test, the coating layer either eroded or abraded to create a surface wherein which less Ra has been recorded. From table 4 it is clear that as the coating thickness increases the roughness value decreases.

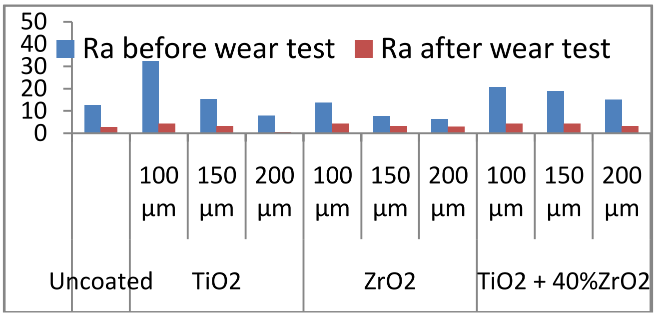

Fig 9: Surface Roughness of uncoated and coated specimens

3.3 Micro Hardness Measurement

The micro-hardness values for different coating powders are listed in Table 5. From the table it is clear that Titania is having the highest hardness value when compared to other combinations

Table 5: Hardness values of specimens

Specimens	**Vickers hardness number (HV)**
Al-6061T6	121
ZrO_2 Coated	273
TiO_2+ 40% ZrO_2 Coated	317
TiO_2 Coated	776

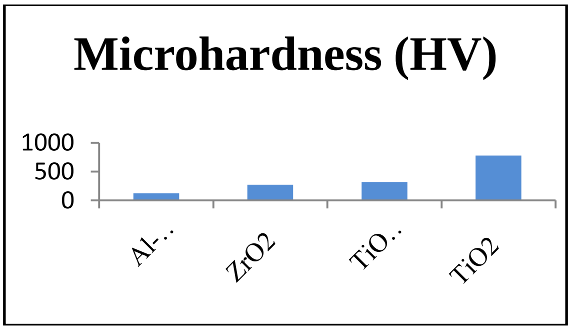

Fig 10: Microhardness of uncoated and coated specimens

3.4 Wear Analysis

A Pin-on-Disc wear test was performed according to ASTM G99-04 standards to simulate sliding wear of the coatings. Figures 11, 12 and 13 shows the effect of sliding distances on wear loss for different powders. Figures 14, 15 and 16 shows the effect of sliding distances on wear loss for different coating thicknesses when compared to Aluminium (Al-6061T6).

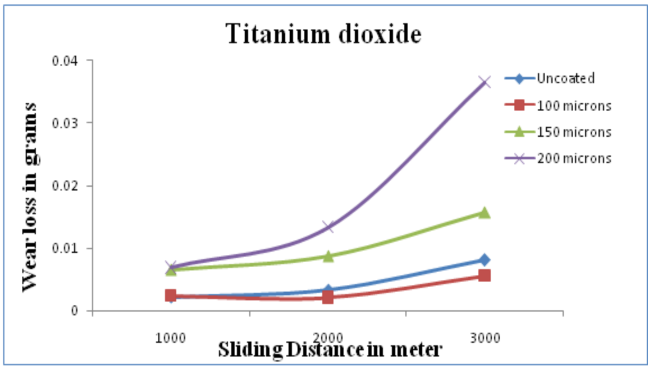

Fig 11: Effect of sliding distance on wear loss for TiO_2

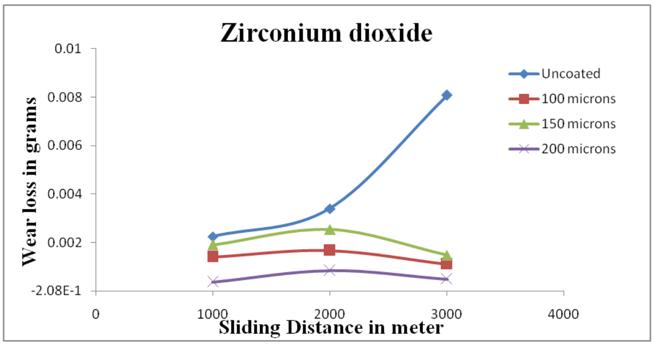

Fig 12: Effect of sliding distance on wear loss for $ZrO2$

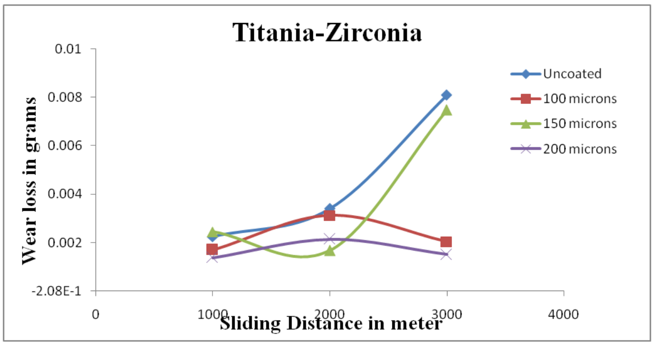

Fig 13: Effect of sliding distance on wear loss for TiO_2-ZrO_2

In the Figure 11, 100 µm is having a minimum wear loss at all the sliding distances compared to bare aluminium and other coating thicknesses. Figure 12 for a sliding distance of 3000m, coated specimens of all the coating thicknesses are having a minimum wear loss when compared to bare aluminium. But 200µm coating thickness is showing minimum wear loss when compared to other coating thicknesses. Figure 13 shows that uncoated (bare aluminium) specimen is showing higher wear loss at all sliding distance when compared to all coating thicknesses. The 150µm is also having the maximum wear loss at a sliding distance of 1000m and 3000m when compared to other coating thicknesses. The 200µm coating thickness is showing the minimum wear loss for a sliding distance of 1000 and 3000m.

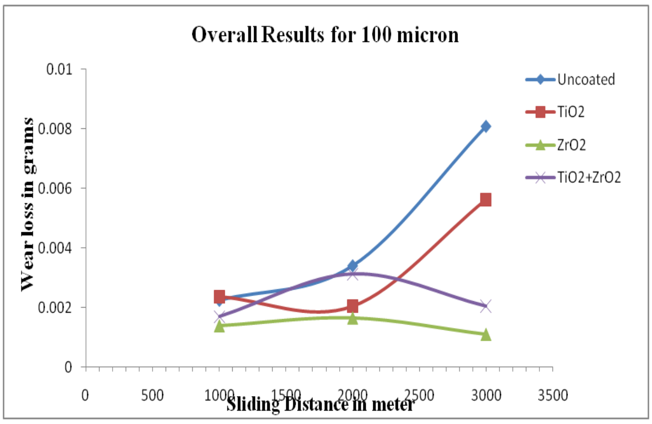

Fig -14: Effect of sliding distance on wear loss for a 100 µm

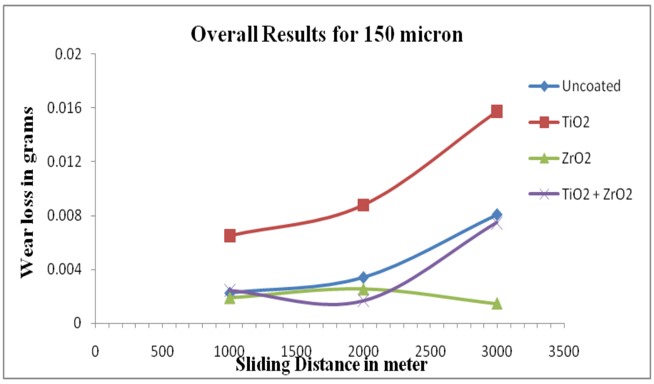

Fig- 15: Effect of sliding distance on wear loss for a 150 µm

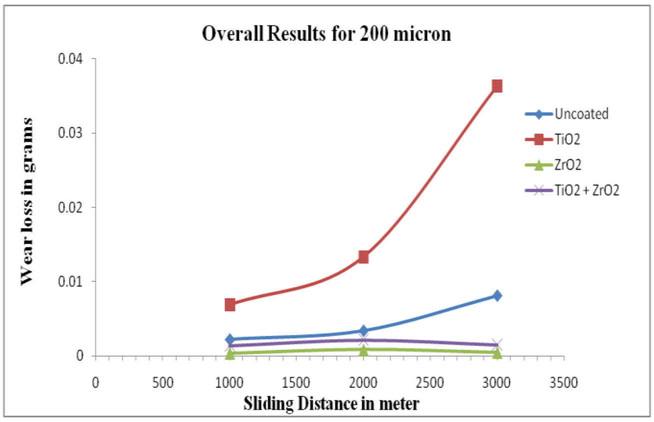

Fig 16: Effect of sliding distance on wear loss for a 200 µm

From figure 14, 15 and 16 shows that ZrO_2 coating is having a minimum wear loss at all three sliding distance when compared to bare aluminium and other coating materials. Figure 17 shows the SEM image of the Al-6061T6 substrate after wear test and Figure 18, 19 & 20 shows the SEM images of coated samples of TiO_2, ZrO_2 and Al_2O_3 +40% ZrO_2 after wear test under a load of 10N at a sliding distance of 3000m. Figure 17 shows that the aluminium substrate has undergone severe wear condition characterized by shearing and plastic deformation and also observed that the substrate [11] surface is weared it causes roughening and the formations of grain (debris). But in Zirconia coated specimen wear track of the substrate observed those scratches and the parallel grooves

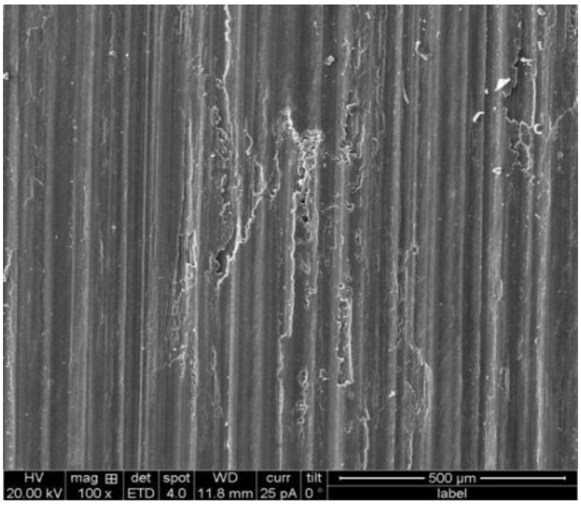

Fig- 17: SEM of Al-6061T6 specimens after wear test

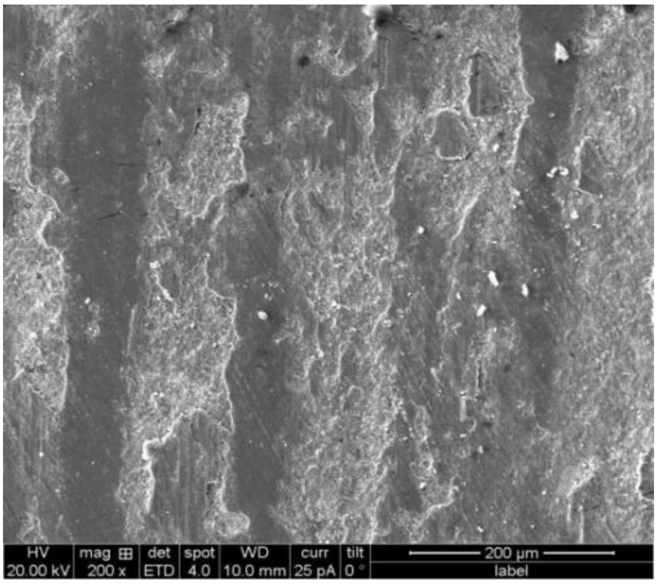

Fig 18: SEM of TiO_2 coated specimens after wear test.

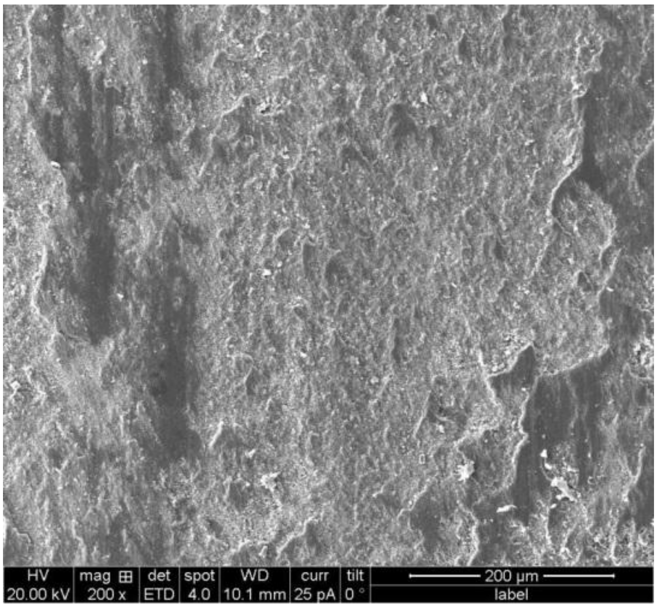

Fig 19: SEM of ZrO_2 coated specimens after wear test

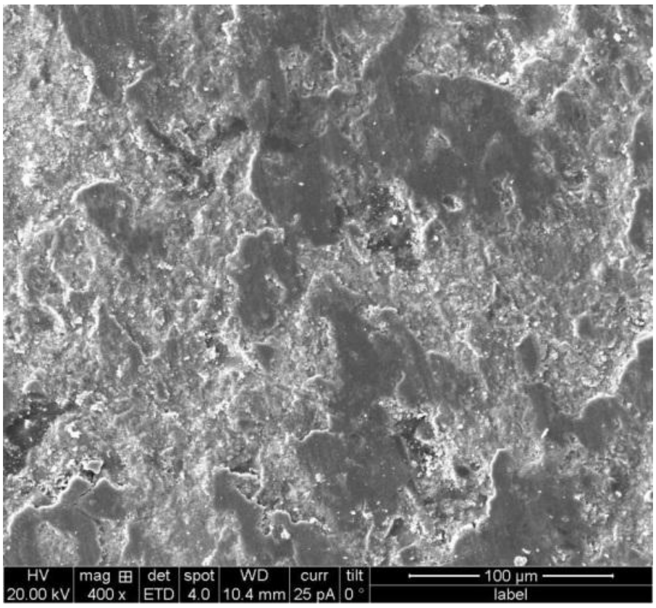

Fig-20: SEM of TiO2+40%ZrO2 coated specimens after wear test.

4. CONCLUSIONS

The conclusions drawn out from the paper are,

- Titania, Zirconia and Titania-Zirconia coatings are deposited on metal substrates with an intermediate bond coat of NiCrAl by atmospheric plasma spraying and these bond coatings exhibit desirable coating characteristics like adhesion strength is a important factor in Thermal Barriers applications.
- ZrO_2 can significantly increase the bonding strength of Plasma-sprayed techniques than that of TiO_2.
- The Zirconia coated specimens showed excellent wear property when compared to other coating materials due to the proper adhesion of Zirconia than that of Titania.
- From figure 5.1 to 5.6 we can conclude that ZrO_2 is having a better performance than that of TiO_2+40%ZrO_2 and TiO_2. Also the combination of TiO_2+40%ZrO_2 gives better result when compared to TiO_2.
- The SEM of the worn surfaces of coated specimen shows that the surfaces are much rougher than that of bare aluminium which can withstand maximum wear than that of the actual Al-6061T6.
- There is no simple relationship between the wear resistance and the hardness, (of the TiO_2/ZrO_2 coatings). It can be suggest that the abrasive wear resistance of the TiO_2/ZrO_2 ceramic coatings is strongly dependent on the toughness of the coatings and the process of structural change in the coatings during wear, as well as the density and the hardness of the coatings.
- By this we can conclude that the Thermal Barrier Coating will increase the wear resistance than that of the any parent metal subjected to wear.

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BIOGRAPHIES

Sachin Jadav N received B.E degree in Mechanical Engineering from Visvesvaraya Technological University Belgaum, Karnataka India, in 2012 is pursuing M. Tech degree in Machine Design from Visvesvaraya Technological University, Belgaum, Karnataka India, 2012-14.

Dr. C Anil Kumar B.E Mechanical Engineering, M.E Production Tech. Ph.D Dr. M.G.R. Edu & Research Institute, Chennai 600 095 India, I have published 6 international and 1 national reputed journals and 13 International / National conferences.