Dry sliding wear behaviour of WC-Co coating on Ti6Al4V using Thermal Spray coating technique

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Abstract
The titanium alloys are extensively using in defence, aerospace, automobile, chemical plants and biomedical applications due to their very high strength and lightweight properties. The most commonly used titanium alloy is the two phase Ti6Al4V. But, it has poor wear and corrosion resistance when exposed to different environment conditions. In this work, surface coatings were applied on Ti6Al4V substrate using high velocity oxy fuel (HVOF) to improve wear characteristics. The ceramic coating (WC–Co) were deposited on Ti6Al4V substrate with different thicknesses 300μm, 400μm and 500μm.

In the present investigation, hardness of both coated specimens and substrate were found by conducting Vickers hardness test. The cross sectional and surface morphology of substrate and coated system with varying thickness were made using SEM.

Pin-on-disc tests are performed for evaluating sliding wear behaviour of substrate and coated system where the counter disc was made of chrome steel. Wear test was carried out at different sliding distances of 1000m, 2000m, 3000m and 4000m at a constant load of 50N and the disc speed was recorded as 600rpm. The mass loss of substrate material and coated system was measured for all the test conditions to demonstrate the wear behaviour. SEM analysis showed the wear behaviour of coated and uncoated samples. The mass loss of the above test conditions expressed that the coating system found to be better improvement in wear resistance of substrate. However, the thicker coat samples (500μm) shows maximum hardness and highest wear resistance.
Keywords: Ti6Al4V, HVOF, WC-Co, wear, hardness.

1.Introduction

Thermal sprayed coatings are used in a wide range of other applications such as the gas turbine, petroleum, chemical, paper/pulp, automotive and manufacturing industries. Metals, carbides and cermets are the most widely used coating materials. The most familiar thermal spray techniques such as high velocity oxy fuel (HVOF) process and detonation spray (DS) or detonation gun (D-gun) spraying system. Selection of coating material, coating technique and the process parameters is an important factor, which influence the tribological performance.

2.Literature Review

Tungsten Carbide with different compositions of Cobalt such as WC–12%Co, WC–20%Co and WC–6%Co coatings were deposited on steel MoCN315M by Y. Wang [1] using D-gun spray and plasma-spray.

Surface coating technology can efficiently and economically improve the properties of metals such as wear resistance, corrosion resistance and high temperature oxidation resistance, etc. [2,3]

M. Magnani et al. [4] fabricated WC–Co coatings on an AA 7050 aluminium alloy using HVOF technology to improve wear resistance. H. Zhang et al. [5] deposited WC–24% Cr3C2–6%Ni coatings by HVOF. They reported that the thermal spray cermet coatings improved wear resistance compared to the substrate material.

J. K. N. Murthy et al. [6] analyzed the abrasive wear behaviour of WC–CoCr and Cr3C2–20(NiCr) deposited by HVOF and D-gun spray processes. They reported that the DS coating performs slightly better than the HVOF coating possibly due to the higher residual compressive stresses induced by the former process and WC-based coating has higher wear resistance in comparison to Cr3C2-based coating.

G. Sundararajan et al. [7] evaluated the tribological performance of 200μm thick TiMo(CN)–28Co and TiMo(CN)–36NiCo coatings obtained by using the D-gun spray coating system. They concluded that the coatings with the highest hardness did not exhibit the best tribological performance.

Deepak Kumar Goyal et al.[8] compared the HVOF sprayed WC-Co-Cr coatings to CoNiCrAlY coatings with respect to erosion. This is generally owing to the greater hardness compared to bond coating of Journal Pre-proof 4 sprayed HVOF deposition.

3.Experimental setup

Ti6Al4V is used as substrate, WC–Co is coated on substrate material in order to improve the wear resistance. Examination and assessment of the coating microstructures in terms of surface morphology, porosity, cracks, chemical composition and phase constituents was carried out using scanning electron microscopy (SEM)/energy-dispersive X-ray spectroscopy (EDX), Optical microscopy(OM) and x-ray diffraction (XRD).The hardness of the coatings and substrate was measured by using Vickers Microhardness Tester. The surface roughness of substrate after grit blasting and after coating. The wear resistance of the as-coated samples were evaluated using pin-on-disc apparatus.

3.1 Materials

In the present study, Table 1 shows the chemical composition of Ti6Al4V substrate. This alloy widely used in chemical plants, automobile, aerospace industries and medical applications (bone, dental). WC–Co powders with an average particle size of 30 are used as coating material whose chemical compositions presented in Tables 2. The feedstock powders were produced by an agglomeration method. In the present investigation, WC–Co powder was used as with varying average coating thickness from 300 to 500μm.

Table 1 Chemical composition of Ti6Al4V

TI	AL	V	FE	C	MO	CR	O	N	H
Bal	6.52	4.17	0.16	0.013	0.03	0.01	0.17	0.006	0.0011

Table 2 Chemical composition of WC–Co powder

WC	CO
94	6

3.2 Base Material Preparation

The substrate of size 25mm length and 10mm diameter bare specimens with one of its surfaces were grit blasted with alumina grits of grit size 70 and pressure about 90PSI, using pneumatic type grit blasting equipment shown in Figure1, followed by an ultrasonic cleaning in acetone to attain enough surface roughness for the best adhesion between coating and substrate.

Figure 1 Grit blasting equipment

3.3 HVOF Technique

HVOF technique utilizes a combination of oxygen with various fuel gases including hydrogen, propane, propylene even kerosene. In the combustion chamber, burning by-products are expanded and expelled outward through an orifice at very high velocities. HVOF coatings may be as thick as 12mm and the lowest possible thickness can be set to 30–400μm per shot. The spray distance ranges 50mm to 500mm. The gun speed can be regulated from 5mm/sec to 50mm/sec. The number of shots per sec ranges 1 to 10. The HVOF process set up is shown in Figure 2.

Figure 2 HVOF process set up

In the present study, HVOF technique was used to deposit WC–Co coat with varying coating thickness. The standard process parameters used for HVOF

Table 3 Process parameters for HVOF

PARAMETER	QUANTITY
Oxygen flow rate (l/min)	350
Gas flow rate (l/min)	12 (Acetylene)
Spray distance (mm)	360
Sample speed (m/s)	2.5 m/s
Gun speed	10 mm/s

3.4 Testing and Characterization

Figure 3 Vickers digital hardness tester DHV-1000

Hardness test and wear test are carried out since the wear is the function of hardness. In order to characterize uncoated and WC-Co coated surface, hardness tests are performed by using Vickers digital hardness tester DHV-1000 as shown in Figure 3

Pin-on-disc tests are used for evaluating sliding wear behaviour. The basic configuration of the wear test equipment (Model: Ducom TR 20) is shown in Figure 4. It consists of a pin in contact with a rotating disc. Either the pin or the disc can be the test piece of interest. The contact surface of the pin could be spherical, or flat. These experiments were conducted in accordance with ASTM G99

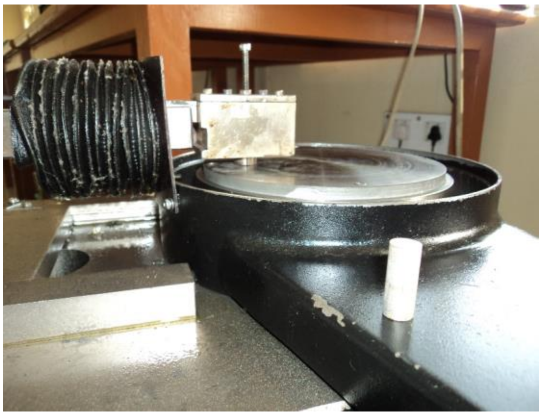


Figure 4 Pin-on-disc apparatus

The wear tests were carried out at 50N, sliding speed maintained at 600rpm and performed at different sliding distances of 1000, 2000, 3000 and 4000m. All wear experiments were carried at room temperature (30–36°C) without any lubrication. The samples after wear test are shown in Figure 5. Weight of the specimens before and after the experiment was taken with help of photoelectric balance shown in Figure 6 with an accuracy of ± 0.1mg.

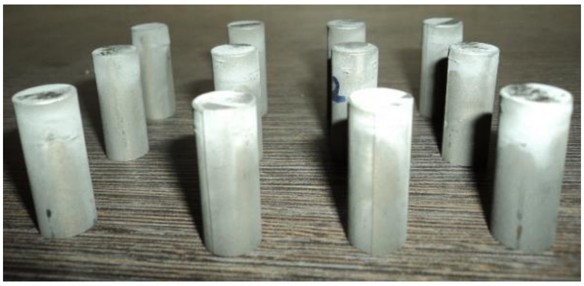


Figure 5 coated samples after wear test

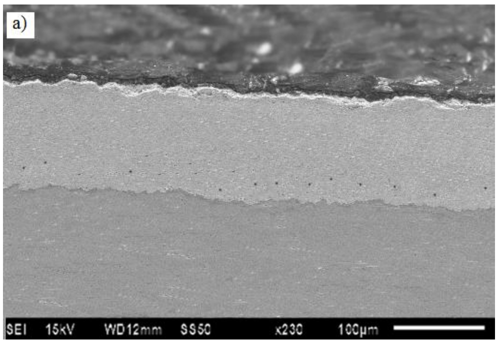
Figure 6 Photoelectric balance

The morphology and porosity. In the present study, JSM-6610LV Scanning electron microscope (SEM). X-ray diffraction patterns of the as-coated samples were taken using an Ultima IV X-ray diffractometer with CuKa radiation and Ni filter.

4. Results and Discussion

The WC-Co coatings are deposited by melting, partially melting and un-melting of powder particles which are sprayed at high velocity on the substrate (Ti6Al4V), using a HVOF technique. Figure 7 a-c shows a typical cross sectional view of WC-Co coating with varying coat thickness. The coating thickness was measured on the SEM micrograph.

The mechanical bonding between the WC-Co coatings can be clearly seen.



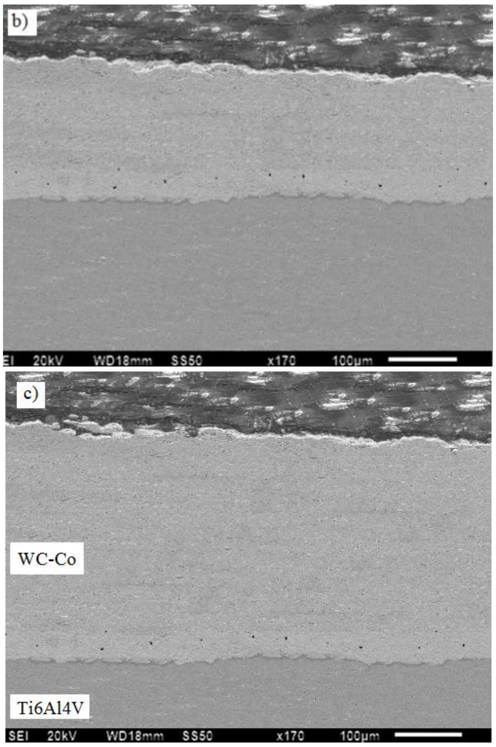
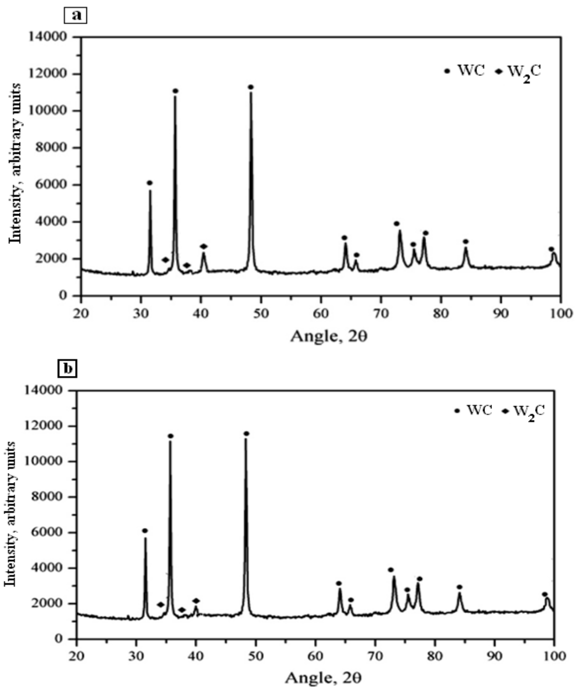


Figure 7 Cross sectional SEM micrographs with varying top coat thickness a) 300µm b) 400µm and c) 500µm

The XRD pattern of HVOF sprayed WC–Co coatings are shown in Figure 8 a-c. Peaks corresponding to WC and W2C are clearly seen in all the three cases i.e. 300µm, 400µm and 500µm thick coated samples. The presence of W_2C in HVOF coatings is due to undesired decarburisation of WC.



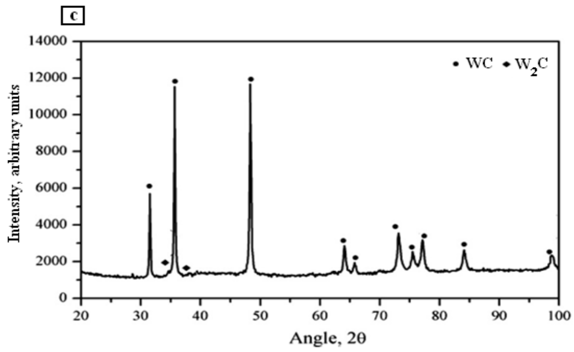


Figure 8 XRD patterns of WC-Co coatings a) 300μm b) 400μm c) 500μm

The microhardness increased with increasing coating thickness, which can be attributed to reduction in porosity during deposition of coatings. The increase in wear resistance can be attributed to the increase in hardness which results from hard WC particles on the substrate.
The microhardness of the substrate is found to be 324HV and that of 300μm,400 μm and 500 μm coated sample is 1215HV, 1257 HV and 1294 HV.

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. A constant load of 50N was applied, the disc speed was set to 600rpm and the radius of the pin location on disc to be fixed. Time of sliding was calculated from the above fixed parameters in order to test at different sliding distances of 1000, 2000, 3000 and 4000m.

Table 4 shows the variation of mass loss of the substrate and WC-Co coatings for different sliding distances. The mass loss of the WC-Co coatings decreased with the increased coating thickness.

Table 4 Variation of mass loss

SD	SUBSTRATE	300μM	400 μM	500 μM
1000	0.825	0.1728	0.17	0.163
2000	0.925	0.204	0.198	0.185
3000	0.964	0.217	0.206	0.178
4000	0.963	0.223	0.21	0.177

* SD- Sliding distance in meters

The worn morphology of 300μm, 400μm and 500μm WC–Co thick coating at 4000m of sliding distance is shown in Figure 9 a-c. The worn morphology of 300μm, 400μm shows significant micro-abrasion type wear. However, 500μm coated samples demonstrated no severe deformation and narrower wear tracks than the other two coated samples (300 and 400μm).

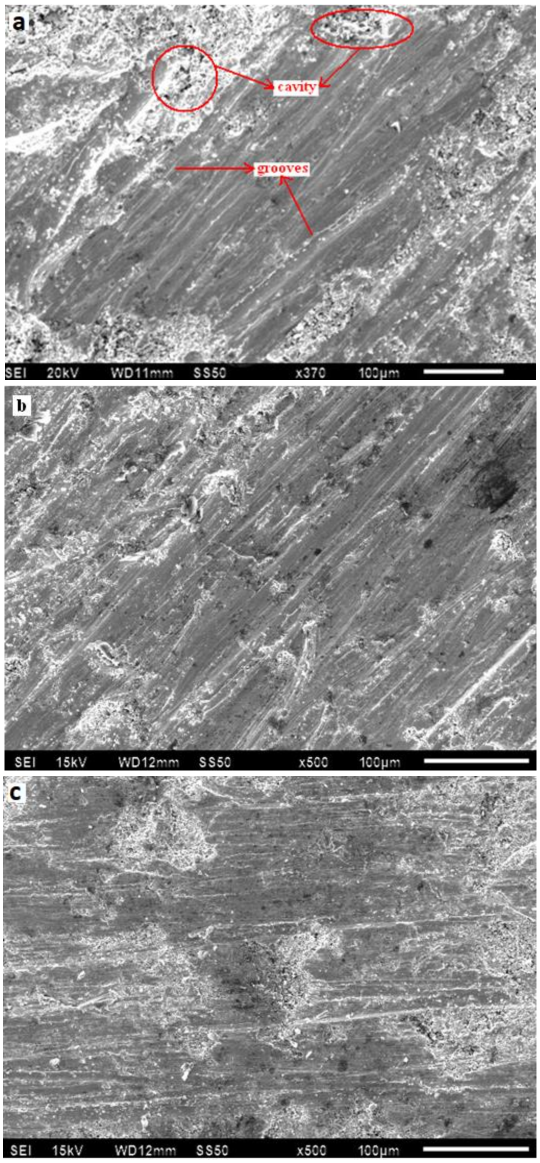


Figure 9 Worn morphologies of a)300µm, b)400 µm and c)500 µm for 4000m sliding distance

5. Conclusion

The Vickers microhardness of Ti6Al4V substrate was 324.

The Vickers microhardness of 300µm thick coated samples was 1215. The microhardness increased with increased top coat thickness. It was observed that the microhardness increased by 3.45% and 6.5% respectively for 400 and 500µm thick coated samples.

The mass loss of the Ti6Al4V substrate was 0.825gm and the mass loss of the 300µm thick coated sample was 0.1728gm at a sliding distance of 1000m and at a load of 50N. The mass loss decreased with increased coating thickness. Finally, the 500µm thick coated samples shows highest wear resistance.

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