Tribological Behavior of WC-Co/NiCrAlY Coatings on Ti-6Al-4V

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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 wear resistance. In the present investigation, duplex coatings were employed to enhance the mechanical and tribological properties. WC-Co Ceramic coatings were deposited on Ti6Al4V substrate with different thicknesses (250µm, 350µm and 450µm) by the detonation spray (DS) while the thickness of the NiCrAlY bond coat (200µm) deposited by High Velocity Oxy Fuel (HVOF), stayed the same. Mechanical properties (hardness and wear resistance) were found for both substrate and duplex coatings. Wear test was performed for different sliding distances (1000m,2000m,3000m and 4000m) at a constant load of 50N by using a pin-on-disc apparatus, and the disc speed was recorded as 600rpm. XRD characterization was performed for substrates and coated samples. SEM analysis showed the wear behavior of coated and uncoated samples. Finally, it was concluded that 450µm ceramic top coat samples resulted maximum hardness and highest wear resistance.

Keywords: duplex coatings; ceramic coatings; Ti-6Al-4V, wear

1. Introduction

Thermal barrier coatings (TBCs) are often deposited on metals to improve mechanical and tribological properties. Detonation spray(DS) is a thermal barrier coating technology expelling the melting or semi-melting state powder heated by the combustion of fuel and oxygen to the surface of working piece at a high speed, which has been extensively used in many fields, such as aviation, space flight, petroleum, metallurgy and other chemical and machinery industries[1-2].This D-gun thermal barrier coating gives an extremely good adhesive strength, low porosity and coating surfaces with compressive residual stresses [3-4].On other hand, High velocity oxy-fuel (HVOF) process belong to the thermal barrier coating technologies group and are capable of producing coatings with higher hardness, superior bond strength and less decarburization during spraying than many of the other thermal spraying methods [5-7]. The main advantage of HVOF process is the shorter residence time in the flame and the higher kinetic energy of the particles impacting. This produces a dense coating with less degradation of the powder during spraying [8]. NiCrAlY was the metallic binder, which improves the toughness of the coating. Ni–Cr alloy is generally used as the metallic binder for providing good corrosion and wear protection at high temperatures. Chromium carbide powder with different proportions of Ni–Cr binder phase has been used for various applications to provide resistance against wear [9-10]. Both the HVOF and DS techniques were used for duplex coating on Ti6Al4V substrate. NiCrAlY bond coat of thickness 200µm was sprayed on Ti6Al4V substrate by using High Velocity Oxy Fuel (HVOF) and followed WC-Co top coat with different thicknesses of 250 µm, 350 µm and 450µm by using Detonation Spray (DS).Hardness of both substrates and coated specimens were found by conducting hardness test. By using pin-on-disc apparatus, wear test was performed for different sliding distances (1000m,2000m,3000m and 4000m) at a constant load of 50N and the disc speed was recorded as 600rpm.

2. Experimental Work

2.1. Materials and Coating Deposition

Titanium alloy (Ti6Al4V) was used as the substrate. NiCrAlY and WC-Co was used as coating materials. The chemical compositions of NiCrAlY powder and WC-Co powder were presented in Table 1 and Table 2 respectively with an average particle size of 30µm as shown in Figure 1. In the present investigation duplex coating was performed with NiCrAlY as the intermediate coat of 200µm thick deposited by HVOF process and WC-Co as the top coat with 250 µm, 350 µm and 450µm thick deposited by the DS process as shown in Figure 2. Prior to deposition the substrate surfaces were grit blasted with alumina grits, followed ultrasonic cleaning in acetone. The grit blasting was performed to get an optimum surface roughness and promote the best attainable adhesion between coating and substrate. The spraying process parameters for HVOF and DS are listed in Table 3.

Table 1. Chemical Composition of NiCrAlY Powder

Constituent	**%**
Cr	22
Al	10
Y	1
Ni	Bal.

Table 2. Chemical Composition of WC-Co Powder

Constituent	**%**
WC	88
Co	12

Table 3. HVOF Process Parameters

Parameter	**HVOF**	**DS**
	Value	
Oxygen flow rate (l/min)	350	35
Nitrogen flow rate (l/min)	12	15
Spray distance (mm)	360	180mm
Sample speed (m/s)	2.5 m/s	2.5 m/s
Gun speed	10 mm/s	15 mm/s

2.2. Characterisation of Coatings

Microstructural characterization studies were conducted on NiCrAlY and WC-Co powder samples and duplex coated samples by using scanning electron microscope. In the present study, 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 diffractometer with CuKa radiation and Ni filter. The XRD analysis was carried out at a voltage of 40 kV and 30 mA current intensity.

2.3. Surface Roughness Measurements

Before conducting the wear tests the surface roughness of pins and the counter face disc were measured. Surface roughness were measured by using Talysurf instrument (Model Softest SJ-301). The cutoff length was 0.8 mm. An average of five readings is reported.

2.4. Microhardness

Microhardness tester model VMHT auto was used to found microhardness of substrate and coated material. Microhardness tests were performed on a cross section of coatings by Vickers hardness testing with a load 300 g and dwell period of 10 s. An average of three readings is reported.

2.5. Wear Testing

The dry sliding wear tests were conducted on a pin-on-disc wear testing machine (Model: Ducom TR 20) according to the ASTM G99-04 standards. The cylindrical pins (10 mm diameter and 25mm height) of the coatings were used as test material. Chrome Steel was used as the counter face material. The wear tests were carried out at 50N at a sliding speed of 600 rpm, over sliding distances of 1000m, 2000m, 3000m and 4000m. Weight losses of the specimens were measured by using a balance with an accuracy of ±0.0001g. The morphology of wear scars was observed by SEM, in order to identify the microstructural behavior and dominant wear mechanisms for both uncoated substrates and as-sprayed samples.

3. Results and Discussion

3.1. Characterisation of Coatings

Figure 1 shows the SEM microstructure of powder samples and SEM cross sectional duplex coating of varying ceramic thickness (250 µm 350 µm and 450 µm) on Ti6Al4V as shown in Figure 2. The XRD pattern of the ceramic top coat is shown in Figure 3. The peaks corresponding to WC have been observed in the pattern. The as-sprayed WC-Co top coat results hard WC particles and during spraying the decarburisation occurs which results in formation of W_2C [11-12]. Figure 4 shows the microstructure of as-deposited condition with a little porosity present in the sample.

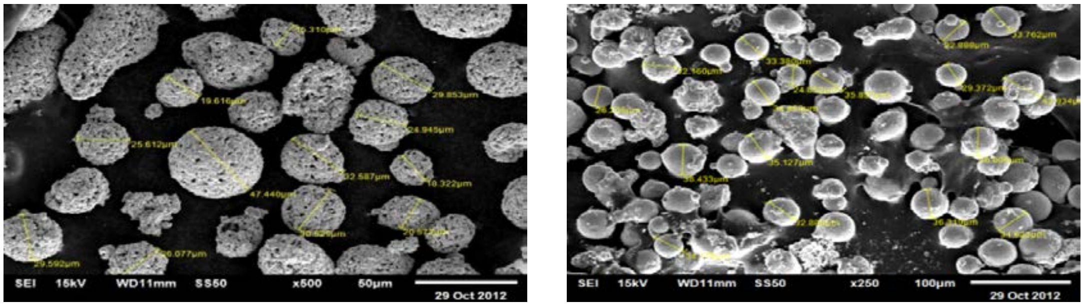

Figure 1. SEM Microstructure of (a)WC-Co (b)NiCrAlY Powders

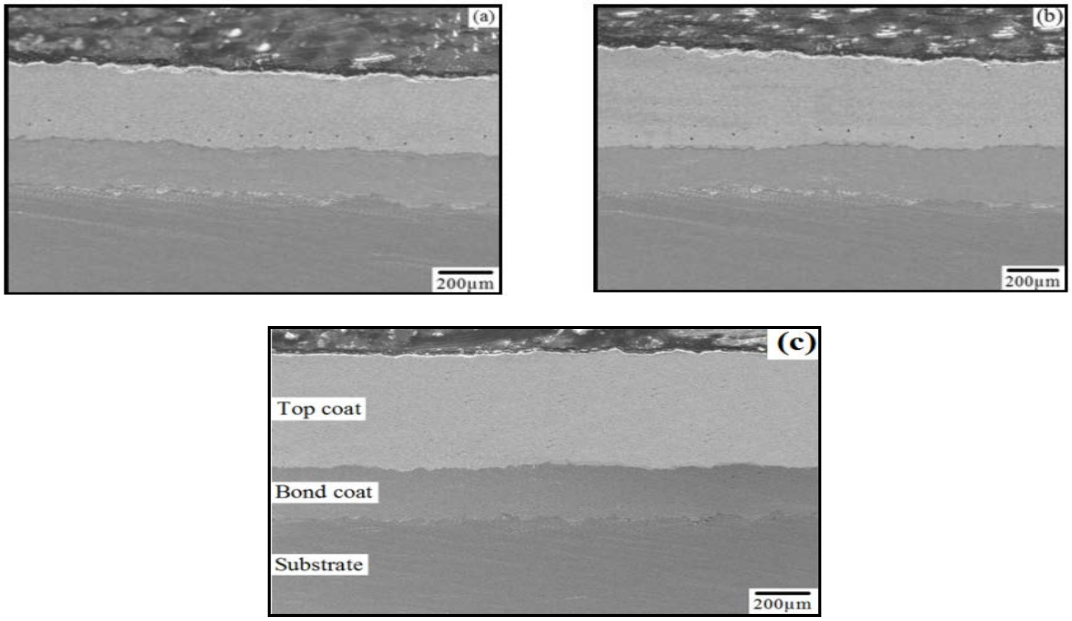

Figure 2. SEM Cross Sectional Duplex Coating of Varying Ceramic Thickness (a)250 µm (b)350 µm (c)450 µm

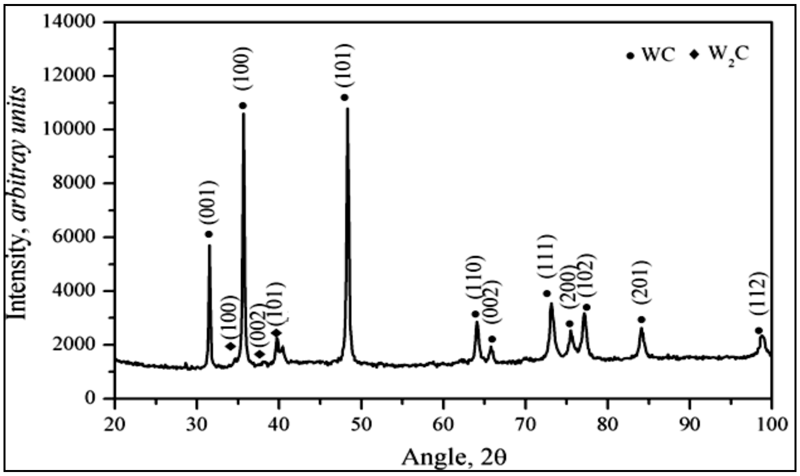

Figure 3. X-ray Diffraction Pattern of WC-Co Top Coat

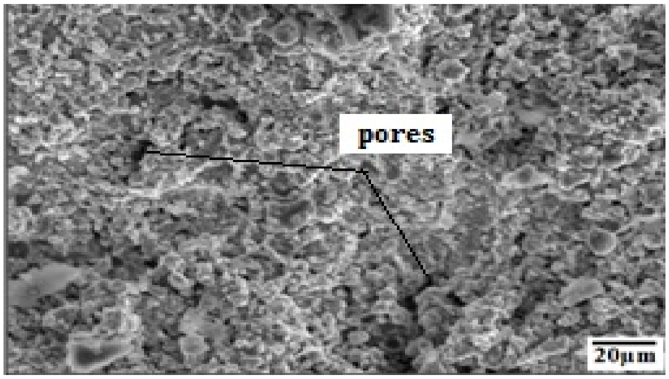

Figure 4. SEM Micrograph of as-sprayed Sample

3.2. Surface Roughness Measurements

Figure 5 shows the variation of surface roughness with the coating thickness. It is observed that the surface roughness decreases with the increase in coating thickness, the decrease in roughness is probably due to the dense coating by the detonation spray process. The corresponding values are given in Table 4.

Table 4. Surface Roughness and Microhardness Measurements with Coating Thickness

Coating thickness (μm)	Surface Roughness Ra (μm)	Vickers Microhardness,VHN (GPa)
250	4.21	1215
350	3.78	1257
450	3.19	1294

3.3. Microhardness Measurements

The microhardness for different coating thickness is shown in Figure 5. It is observed that the microhardness increases with the increase in coating thickness. The increase in microhardness can be attributed to the decrease in the porosity as the coating thickness increases due to the dense coating.

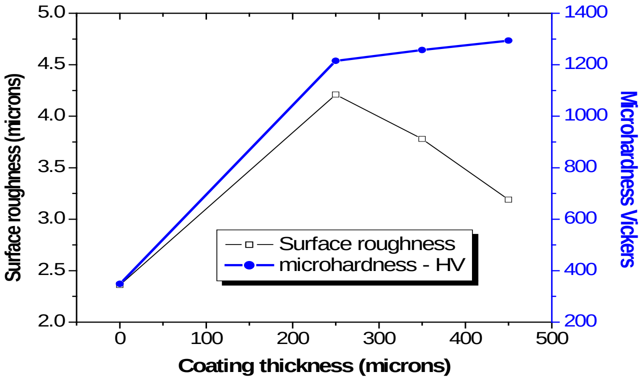

Figure 5. Variation of Surface Roughness and Vickers Hardness with Coating Thickness

3.4. Wear 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. A constant load of 50N was applied and the disc speed was 600 rpm, 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 1000m, 2000m, 3000m and 4000m. The mass losses are shown in Figure 6 for different sliding distances. However, the mass loss trend is similar for all the coating thicknesses, but it is evident that the mass loss increases suddenly up to a sliding distance of about 1000m. After this initial where there is only a little increase in remaining sliding distance. This can be attributed to the strain hardening in the disc material and coated sample, thereby reducing the mass loss with the increase in sliding distance. However, to explain the wear mechanism, 450µm thick coated sample was used for SEM analysis.

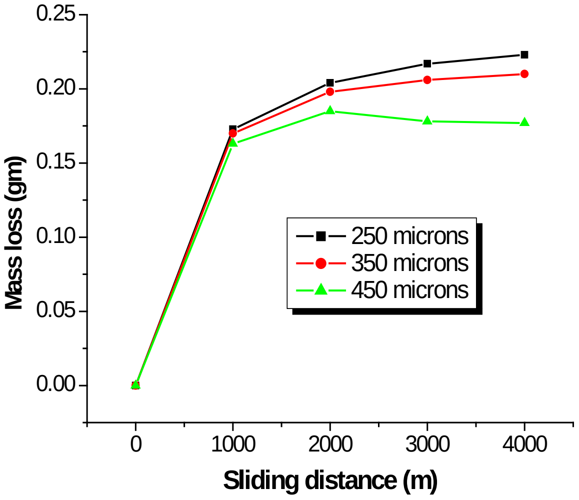

Figure 6. Variation of Mass Loss as a Function of Sliding Distance with Coating Thickness

Figure 7 shows the wear track morphologies of substrate and coated sample with ceramic thickness 450µm subjected to sliding wear under a load of 50N at a sliding distance of 1000m. Figure 7a 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 7b). The wear track shows evidence of limited micro-cutting but a significant brittle fracture of the coating.

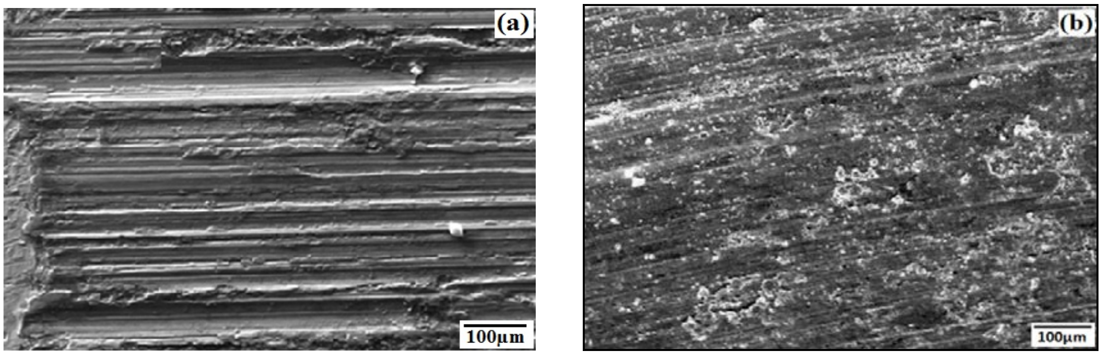

Figure 7. SEM Worn Surfaces of (a) Substrate (b) Coated Specimen with Ceramic Thickness 450µm

4. Conclusions

- Duplex coating on Ti6Al4V substrate was successfully employed.
- The wear resistance is the function of hardness, but at different sliding distances the specimens with 250µm, 350µm and 450µm showed similar trends in mass loss.
- The mass loss increases suddenly up to a sliding distance of about 1000m.After this initial wear there is only a little increase in remaining sliding distance.
- The substrate is subjected to a severe wear characterized by plastic deformation, shearing and abrasion.
- The wear track of the duplex coated sample shows the evidence of limited micro-cutting but a significant brittle fracture of the coating.

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References

[1] C. Jia, Z. Li and Z. Xie, “A research on detonation gun coating with Fe–SiC composite powders mechanically activated”, Materials Science and Engineering:A, vol. 263, no. 1, **(1999)**, pp. 96-100.

[2] P. Saravanan, V. Selvarajan, D. S. Rao, S. V. Joshi and G. Sundararajan, “Influence of process variables on the quality of detonation gun sprayed alumina coatings”, Surface and Coatings Technology, vol. 123, no. 1, **(2000)**, pp. 44-54.

[3] Y. A. Kharlamov, “Detonation spraying of protective coatings Materials”, Science and Engineering, vol. 93, **(1987)**, pp. 1-37.

[4] T. Morishita, E. Kuramochi, R. W. Whitfield and S. Tanabe, “Coatings with compressive stress”, Proceedings of the International Thermal Spray Conference, Orlando, OH, **(1992)**, pp. 1001-1004.

[5] L. Pawlowski, “The Science and Engineering of Thermal Spray Coatings”, John Wiley & Sons, Chichester, England, **(1995)**.

[6] R. W. Smith and R. Knight, “Thermal spraying I: Powder consolidation: From coating to forming”, JOM, vol. 47, **(1995)**, pp. 37-39.

[7] B. Qian Wang and Z. Rong Shui, “The hot erosion behavior of HVOF chromium carbide-metal cermet coatings sprayed with different powders”, Wear, vol. 253, no. 5-6, **(2002)**, pp. 550-557.

[8] J. R. Nicholls, “Designing oxidation resistant coating”, JOM, pp. 52, no. 1, **(2000)**, pp. 28-35.

[9] G. Barbezat, A. R. Nicol and A. Sickinger, “Abrasion, erosion and scuffing resistance of carbide and oxide ceramic thermal sprayed coatings for different applications”, Wear, vol. 162-164, Part A, no. 13, **(1993)**, pp. 529-537.

[10] K. J. Stein, B. S. Schorr and A. R. Marder, “Erosion of thermal Spray MCr–Cr3C2 cermet coatings”, Wear, vol. 224, no. 1, **(1999)**, pp. 153-159.
[11] D. A. Stewart, P. H. Shipway and D. G. McCartney, “Abrasive wear behaviour of Conventional and nanocomposite HVOF-sprayed WC-Co coatings”, Wear, vol. 225-229, no. 2, **(1999)**, pp. 789-798.
[12] S. Usmani, S. Sampath, D. L. Houck and D. Lee, “Effect of Carbide Grain Size on the Sliding and Abrasive Wear Behavior of Thermally Sprayed WC- Co Coatings”, Tribol. Trans., vol. 40, no. 3, pp. 470-478.

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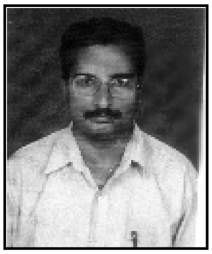

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