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Influence of Critical Plasma Spray Parameter on Microstructural and Tribological Characteristics of Nanostructured Tungsten Carbide-Cobalt Coatings

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Abstract

Nanostructured tungsten carbide-cobalt coatings were deposited by air plasma spraying (APS) technique, using nitrogen as primary plasma gas. The characteristics of nanostructured coatings are typically affected by the percentage of unmelted/partially-melted regions present in the coatings. Hence, the coatings were obtained as a function of critical plasma spray parameter (CPSP), which is defined as the ratio of arc power to the primary plasma gas flow rate. It was observed that tungsten (W) rather than tungsten carbide (WC) was the dominant phase in nanostructured coatings due to decarburization. CPSP was found to have a significant effect on wear performance of APS nano-structured coatings. Wear resistance was highest for coatings deposited at lowest CPSP. Flaking was more prevalent in nanostructured coatings deposited at the highest CPSP.

Keywords: Nano structured coatings, CPSP, air plasma spraying, tungsten carbide-cobalt, wear.

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1. Introduction

Tungsten carbide (WC) coatings are widely used for higher temperatures applications due to their improved abrasive, adhesive, and erosion wear resistance [1-3]. Air/vacuum plasma, high velocity oxy-fuel (HVOF), or warm spraying can be used for depositing these coatings. However, HVOF spraying gives the best performance coatings and is the preferred method [4, 5]. While hard ceramic WC particles provide the wear resistance, the metallic cobalt (Co) binder provides toughness and good adhesion with the substrate on which the coatings are deposited. Several works comparing abrasive/sliding wear resistance of conventional and nanostructured tungsten carbide-cobalt coatings deposited using HVOF spraying show superior performance of conventional coatings over nanostructured counterparts [6-9]. Higher dissolution of WC into cobalt matrix for nanostructured powders, resulting in a less tough matrix phase, has been attributed as the primary cause for greater flaking and higher wear rates in nanostructured coatings. On the other hand, opposite trend has been observed for coatings deposited using air plasma spraying [10]. In this work, microstructural and tribological characteristics of air plasma sprayed nanostructured tungsten carbide-cobalt coatings deposited using nitrogen as primary plasma gas as a function of CPSP are investigated in detail.

2. Experimental procedure

2.1 Coatings deposition

Coatings with a thickness of around 300-350 μm were deposited on AISI 1020 steel substrates of size 65x46x5 mm using a Sulzer Metco 3MB air-plasma spray gun with commercially available nanostructured feedstock powders. Some of process parameters and corresponding equivalent CPSP values are shown in Table.1. During coating process, the material to be deposited is injected in powder form using nitrogen (N_2) as carrier gas. A bond coat of Ni-Al/Ni-Cr is used to improve the adhesion. Nitrogen and hydrogen were used as primary and secondary plasma gases respectively for coatings deposition.

Table1. Process parameters used for depositing coatings.

Current(I) (Amps)	Voltage (V) (Volts)	N_2 gas flow rate (slpm)	H_2 gas flow rate (slpm)	Equivalent CPSP
400	84	50	15	672
400	88	65	20	542
450	90	50	15	810
450	91	65	20	630
500	90	50	15	900
500	92	65	20	707

2.2. Characterization of coatings

The specimens for further analyses of 10x5x5 mm size are polished and then characterized using SEM, FE-SEM, XRD, Vickers micro hardness tester, and Image J software. Large size coated samples are used for conducting wear tests. The Vicker's micro hardness of the as-sprayed coatings is measured at 10 randomly selected positions in the top coat region on the polished cross section of each sample using a Leco Vicker's micro hardness tester (LM700) at 100 g load for a dwell time of 15 seconds. The morphology of the as received feed stock powders and the microstructure of the coatings are also analysed using ZEISS (ZEISS EVO 60) scanning electron microscope (SEM) coupled with an energy dispersive x-ray analyser (Oxford Instruments, UK). The wear tests are conducted on as-sprayed coatings using Ducom Tribometer (wear and friction monitor, TR-20-M24).

3. Results and Discussion

3.1. Coating microstructure and phase distribution

Typical coating microstructures of nanostructured tungsten carbide-cobalt coatings deposited at CPSP 511 and 765 are shown in Figure 1 (a-b). The following observations can be made from Figure 1: (i) Inter splat bonding appears to be weak for nanostructured coatings deposited at lowest CPSP of 511, (ii) As expected, percentage of unmelted, sharp edged, sub-micron, tungsten-carbide particles in partially melted regions is highest at lowest CPSP, (iii) Shape, orientation, and degree of bonding of partially melted regions with surrounding matrix, depend on fraction of unmelted particles within the PM region. X-ray diffraction patterns for air plasma sprayed (APS) nanostructured coatings deposited at lowest, and highest CPSPs, are shown in Figure 2 (a-b). It may be noted from the figure that there is a significant decarburization in nanostructured tungsten carbide-cobalt coatings leading to formation of tungsten (W) and brittle W_2C phases.

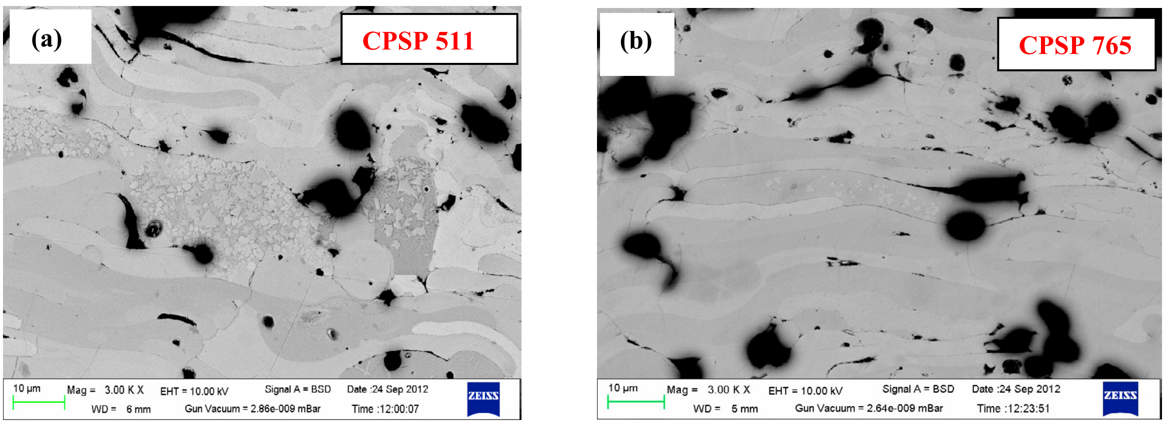
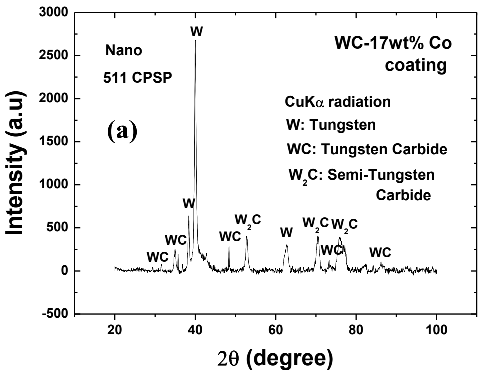


Figure 1 (a-b): Coating microstructures for APS nanostructured tungsten carbide-17wt% cobalt coatings deposited using nitrogen as primary plasma gas at 511and 765 CPSPs, respectively.



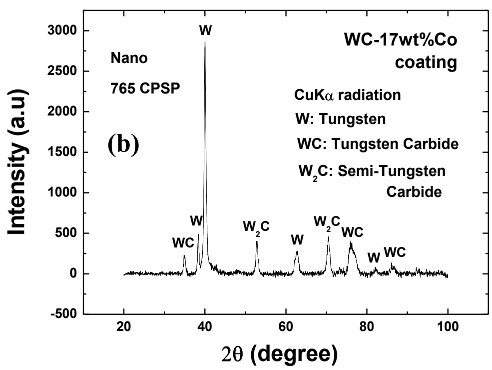


Figure 2 (a-b): XRD patterns for APS nanostructured tungsten carbide-17wt% cobalt coatings deposited using nitrogen as primary plasma gas at 511and 765 CPSPs, respectively.

3.2. Coating wear characterstics

Weight loss of APS conventional and nanostructured tungsten carbide-cobalt coatings in ball-on-disc wear tests, as a function of CPSP, sliding speed and normal load, are shown in Figure 3(a-b). Note from the figure that, there is a strong effect of CPSP on wear performance of nanostructured tungsten carbide-cobalt coatings. Weight loss in all wear tests was found to be lower for nanostructured coatings deposited at 588 than 765 CPSP. The effect is most prominent at the highest sliding speed of 0.5 m/s and highest normal load of 1.5 kgf, considered in this work. It can be seen from the figure that weight loss increases with increasing normal load and increasing sliding speed. Comparison of weight loss of APS conventional and nanostructured coatings deposited at 765 CPSP, shows that nanostructured coatings provide better performance at the lowest normal load (see Figure 3.b). Weight loss in nanostructured coatings deposited at 588 and 765 CPSPs at these conditions (i.e. highest sliding speed of 0.5 m/s and highest normal load of 1.5 kgf) was found to be about 3 and 7 mg, respectively (see Figure 3 c). It can be seen from the figure that weight loss increases with increasing normal load and increasing sliding speed. However, the performance of nanostructured and conventional coatings is similar at higher loads.

Scanning electron microscopy (SEM) images of wear tracks, for wear tests done on nanostructured coatings deposited at 765 CPSP at 1.5 kgf normal load and 0.33, 0.5 m/s sliding speeds, are shown in Figure 4 (a-d). It can be seen from figure that wear track surfaces are drastically different at the two different sliding speeds. While, there is an appreciable wear/material loss at a sliding speed of 0.33 m/s, the degree of damage of the wear track is much higher at the higher sliding speed. At the lower speed micro fracture is visible (Figure 4 b). Increase in degree of pulverisation results in higher weight loss for these coatings (see Figures 3 a).

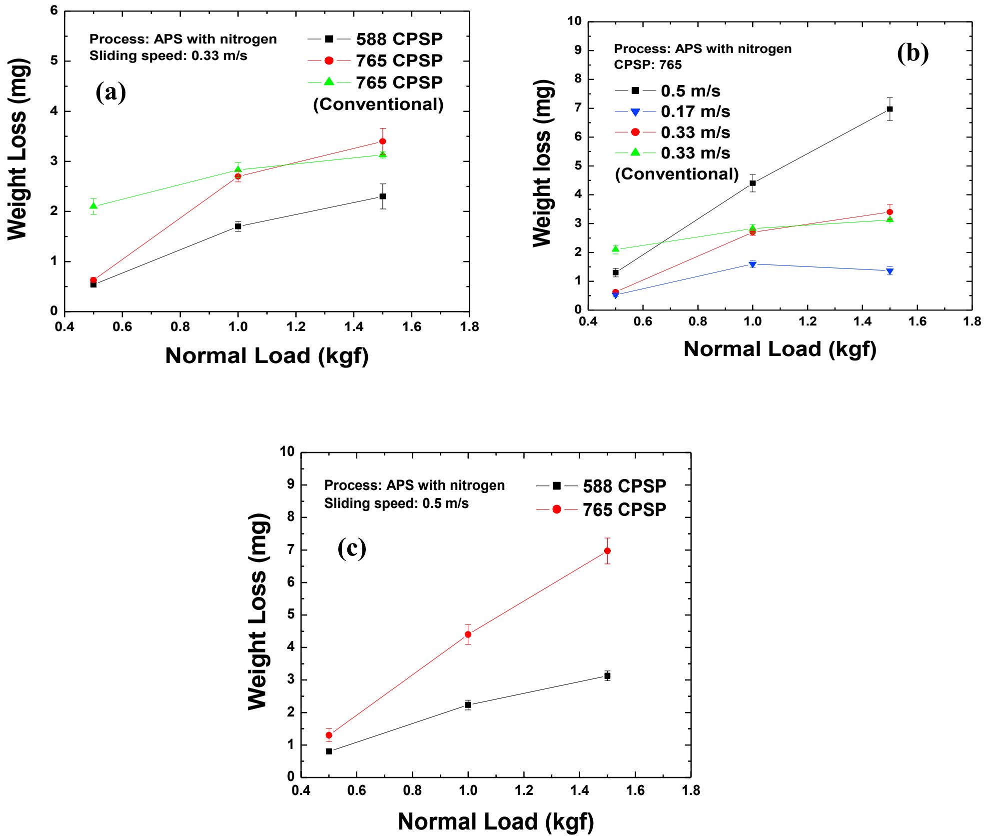


Figure 3 (a-c): Weight loss as function of normal load for air plasma sprayed nanostructured tungsten carbide-cobalt coatings deposited at 588 and 765 CPSPs and corresponding conventional coatings deposited at 765 CPSP at sliding speed of (a) 0.33 m/s (b) at different sliding speeds of 0.17, 0.33 and 0.5 m/s and (c) at sliding speed of 0.5 m/s for coatings deposited at 588 and 765 CPSP.

Effect of CPSP on wear track surface morphologies for nanostructured coatings deposited at intermediary and highest CPSPs (i.e., 588 and 765) can be seen in Figure 5 (a-f). Note that while nanostructured coatings deposited at intermediary CPSP result in *relatively smooth* wear track surfaces with good integrity, those deposited at the highest CPSP result in *flaky, non-smooth surfaces.* In coatings deposited at 588 CPSP, weight loss of the coating appears to be from plastic deformation induced wear. Crack formation, possibly from sliding contact fatigue, can be seen in Figure 5e. Figures 5 d, f show that flaking and pulverization are much more extensive in coatings deposited at highest CPSP than at intermediary CPSP. Higher sliding contact fatigue wear and pulverization (see Figure 5 f) at highest CPSP is believed to be responsible for higher weight loss of these coatings. Lower volume fraction of PM regions in coatings deposited at highest CPSP could also be responsible for their reduced toughness.

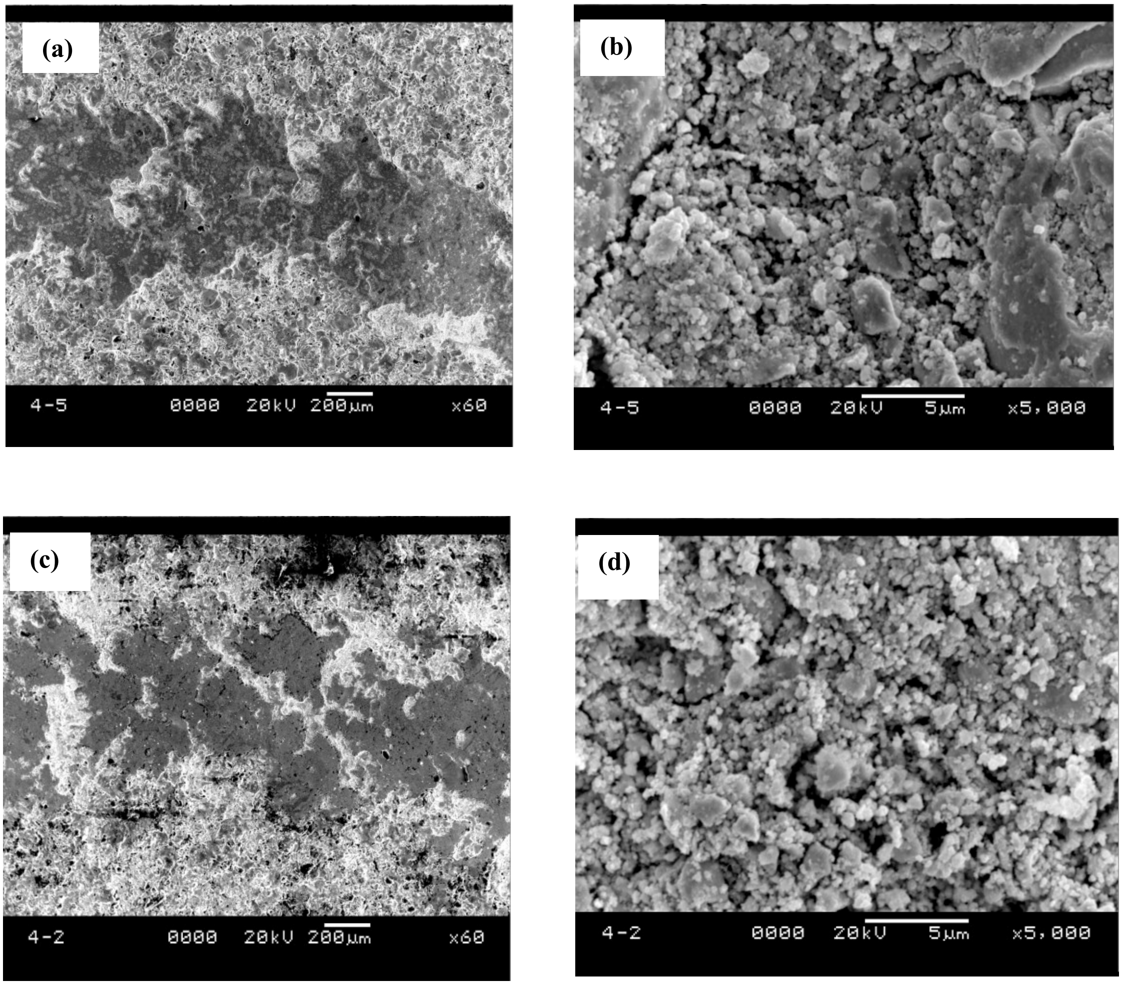


Figure 4 (a-d): Morphology of wear tracks at lower and higher magnifications corresponding to the wear tests done on nanostructured tungsten carbide-cobalt coatings at 1.5 kgf normal load and a sliding speed of (a,b) 0.33 and (c,d) 0.5 m/s, respectively. Note that these coatings were deposited at 765 CPSP using nitrogen as primary plasma gas.

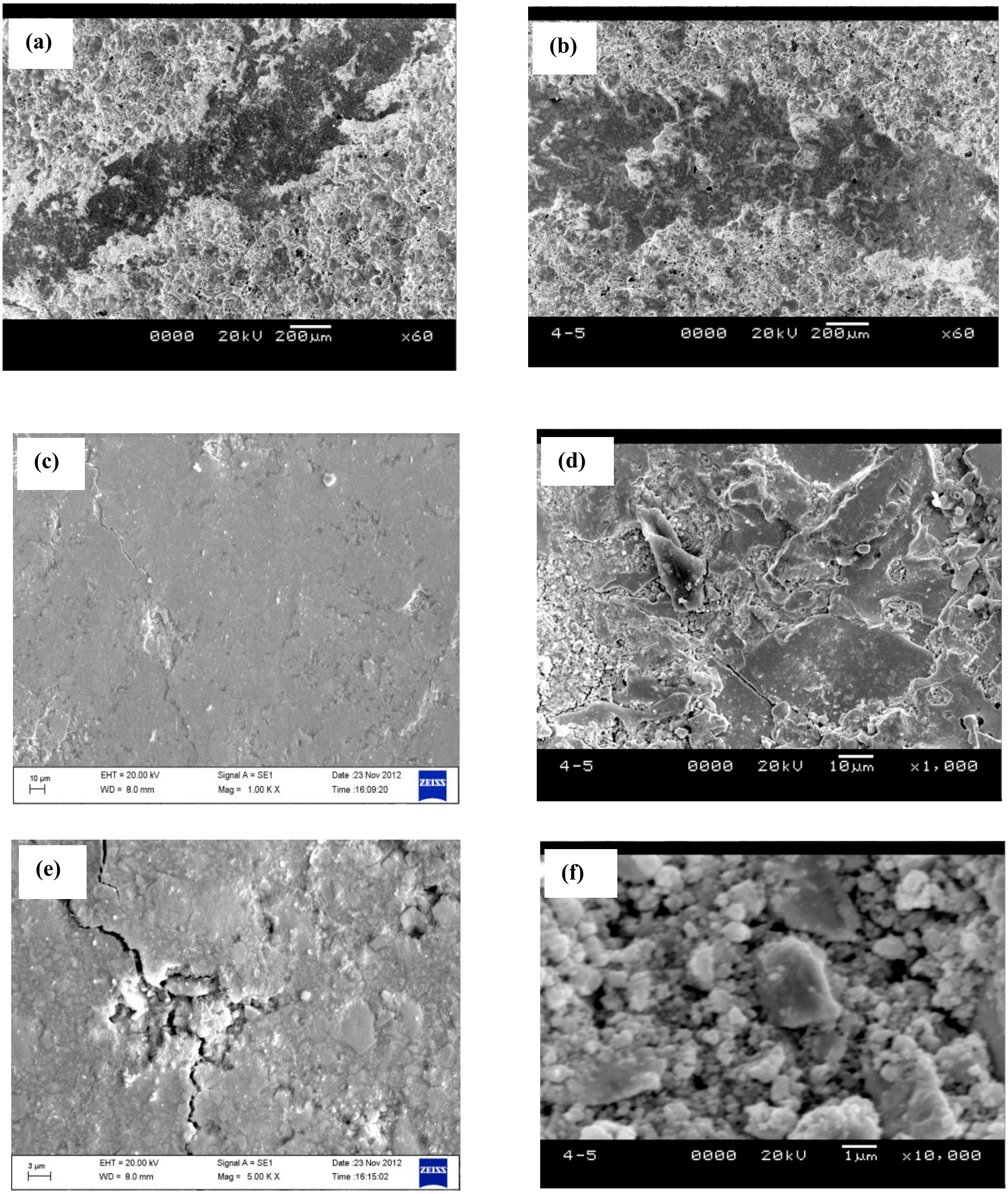


Figure 5 (a-f): Morphology of wear tracks at lower and higher magnifications corresponding to the wear tests done on nanostructured tungsten carbide-cobalt coatings at a sliding speed of 0.33 m/s, normal load of 1.5 kgf and (a,c,e) 588 and (b,d,f) 765 CPSP, respectively.

4. Summary

This paper presents microstructural and wear characteristics of air plasma sprayed (APS) nanostructured tungsten carbide cobalt coatings deposited with nitrogen as the primary plasma gas. The coatings are obtained as a function of critical plasma spray parameter (CPSP). The following are the conclusions drawn from this work:

- Decarburization of WC phase in nanostructured coatings deposited with nitrogen was severe, and consequently W rather than WC was the dominant phase in nanostructured coatings.

- CPSP was found to have a significant effect on wear performance of APS nano-structured coatings. Wear resistance was highest for coatings deposited at lowest CPSP. At highest normal load and sliding speed considered, average weight loss for coatings deposited at the lowest CPSP was about 50% of that for coatings deposited at the highest CPSP.

- Flaking was prevalent in nanostructured coatings deposited at the highest CPSP. It was believed that flaking occurring possibly from sliding contact fatigue is responsible for higher weight loss in nanostructured coatings deposited at the highest CPSP.

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