Special Issue of the 6th International Congress & Exhibition (APMAS2016), Maslak, Istanbul, Turkey, June 1–3, 2016

The Surface Properties of WC–Co–Cr Based Coatings Deposited by High Velocity Oxygen Fuel Spraying

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The aim of this research was to investigate microstructural and mechanical properties of the WC–Co–Cr coatings by high velocity oxygen fuel spraying. Woka 3653 (WC10Co4Cr) powder was used as coating material. This powder is widely used as a tribological coating material providing a combination of high toughness, high hardness, and good strength. The coatings were produced for the different high velocity oxygen fuel spraying parameters. The treated samples were characterized by using scanning electron microscopy/energy dispersive X-ray spectrometry and X-ray diffractometry. Microhardness measurements were executed to evaluate the mechanical properties of the coatings. Also the wear performance of the coatings was investigated. The scanning electron microscopy and energy dispersive X-ray spectrometry analyses were applied to worn surfaces. The results indicated that the coating shows slightly higher microhardness and better abrasive wear resistance than the conventional counterpart.

DOI: 10.12693/APhysPolA.131.186

PACS/topics: 81.15.Rs

1. Introduction

Tungsten carbide (WC) based cemented carbides are widely used for tools, dies and wear resistant parts in variety of applications including machining, mining, metal cutting/forming, construction and other applications in the form of bulk parts or coatings [1]. WC–Co–Cr coatings can be formed using the plasma spraying, explosive spraying, or high velocity oxygen fuel (HVOF) spraying techniques [2, 3].

In the case of plasma spraying, since the temperature of the plasma flame is very high, the WC is easily decomposed, even though the interior of the plasma flame is below the oxidizing atmosphere [2–4]. HVOF spraying, in which oxygen and fuel are combusted to accelerate feed stock powder towards the substrate building up the coating, is the most common process [5]. On the other hand, in the case of explosive spraying and HVOF spraying, since the powder feed rate is sufficiently high, the density, hardness, and bonding strength of the coating layers are superior to those of the layers obtained using plasma spraying [4]. Thanks to the development of HVOF technique, superior wear resistance can be obtained for varieties of complex coating structures.

Major properties of WC–Co–Cr coatings are large hardness, better adhesion and small difference in stiffness between substrate and the top layer part. Indeed, WC–Co–Cr material provides a better distribution of the contact stress and thus avoids severe delamination problems [6–8].

The WC–Co–Cr coatings have been employed to improve the wear resistance and corrosion properties [9, 10]. WC–Co–Cr coatings derive its wear resistant properties from the presence of high volume fraction of hard, wear resistant WC grains in a Co-based metallic binder phase. The presence of the metallic binder provides some toughness in the coating compared to pure ceramic coatings; however, the binder can exhibit some brittleness if high W and C are dissolved in the binder during spraying [11].

In this work, the effects of the coating parameters and wear properties of the HVOF sprayed WC10Co4Cr coating layers were studied. In the HVOF spraying process there were used the different nozzle distances and number of passes.

2. Experimental procedure

For the coating, agglomerated and sintered WC10Co4Cr (86wt%WC–10wt%Co–4wt%Cr) powder was used and provided by Sulzer-Metco and named Woka 3653. Figure 1 shows the scanning electron micrographs (SEM) of the starting WC–Co–Cr powders. The particle sizes of powders are in a range of 10 to 45 μm and have a near spherical form. The powders were sprayed using a high velocity oxy-fuel thermal spray process with a JP-5000 gun and six samples were coated at two different nozzle distances and three different passes (Table I). The substrate used for preparing coatings was rectangular stainless steel. The morphology and microstructure of coatings were examined by optical microscopy and SEM. Phase analysis was performed by XRD analysis technique and microhardness of polished specimens was measured with a load of 300 g for 15 s.

Friction and wear behaviors were investigated by using the reciprocating slide tester by CSM test machine. Wear tests were conducted in a linear wear test machine with in reciprocating sliding mode with a 0.1 m/s and constant sliding speed under 3 N load for 400 m sliding distance.

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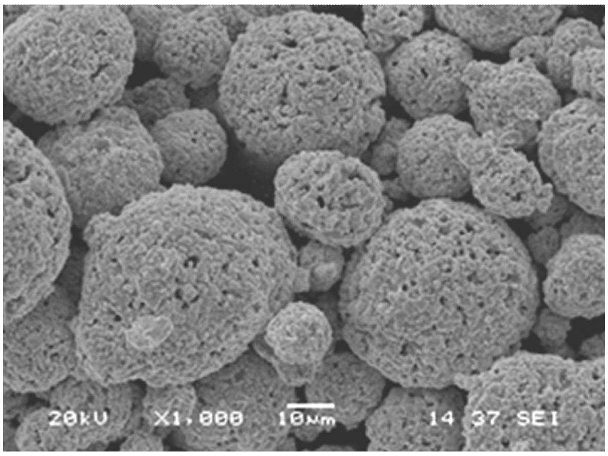

Fig. 1. SEM micrograph of WC10Co4Cr powder.

TABLE I

The parameters of HVOF.

Sample No.	Distance [cm]	Number of passes
1	25	10
2	35	10
3	25	20
4	35	20
5	25	30
6	35	30

Al_2O_3 ball with 10 mm diameter was used as counterpart. The friction force was continuously recorded by sensors at the test block so that the coefficient of friction can be calculated with respect to normal force. All tests were accomplished at room temperature (23±3 °C) and in controlled humidity between 20 and 25%. Before the wear test, the surfaces were polished by alumina suspension. Wear traces were investigated by SEM and EDS.

3. Results and discussion

Figure 2a–f shows the SEM micrographs of the as-sprayed coating microstructure. Here, Fig. 2a,c,e shows the microstructures for 25 cm nozzle distance and Fig. 2b,d,f shows the microstructures for 35 cm nozzle distance. The number of passes increases from Fig. 2a to f. It is observed that coating layers are very dense and have a good contact with substrate due to the higher velocity of HVOF thermal spraying [12]. Also, the coating layer thicknesses increase with decrease of nozzle distance and increase of passes numbers.

WC grains are found to be embedded in Co and Cr binder phase and no significant change is observed in the morphology and particle size of WC grains with changing of nozzle distance and passes numbers (Fig. 3 and Table II).

For all samples, XRD patterns are very similar and have main phase WC and low amounts of W_2C phases (XRD pattern belonging to sample 5 is given in Fig. 4).

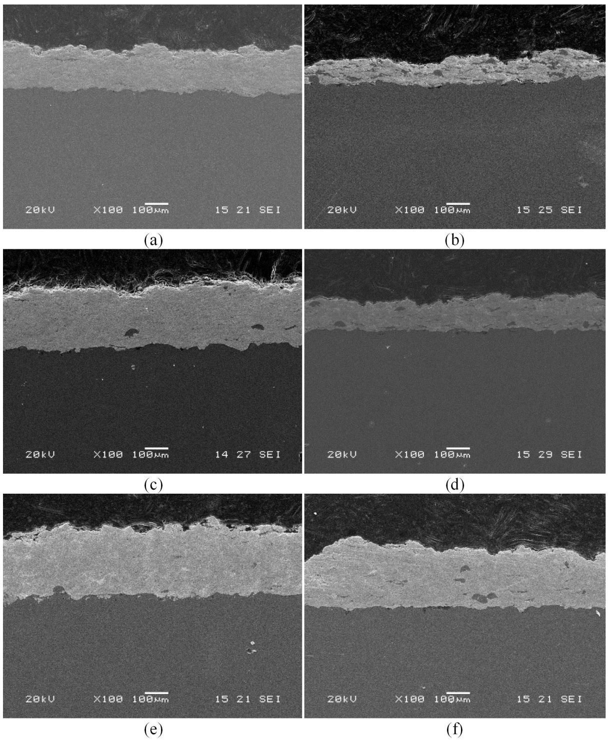

Fig. 2. SEM micrograph of (a) sample 1, (b) sample 2, (c) sample 3, (d) sample 4, (e) sample 5, (f) sample 6.

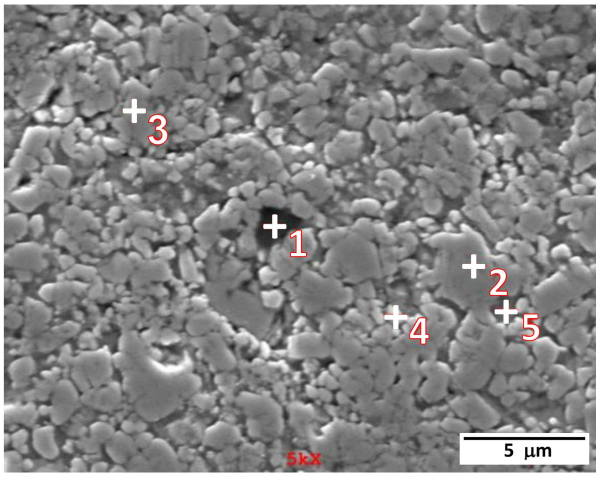

Fig. 3. EDS points of sample 3.

TABLE II

EDS point analysis [wt%] of sample 3

No.	C	Cr	Co	W
1	2.78	55.90	24.18	17.14
2	5.83	–	–	94.17
3	9.95	–	–	90.05
4	3.49	2.37	4.75	89.39
5	–	8.50	24.76	66.74

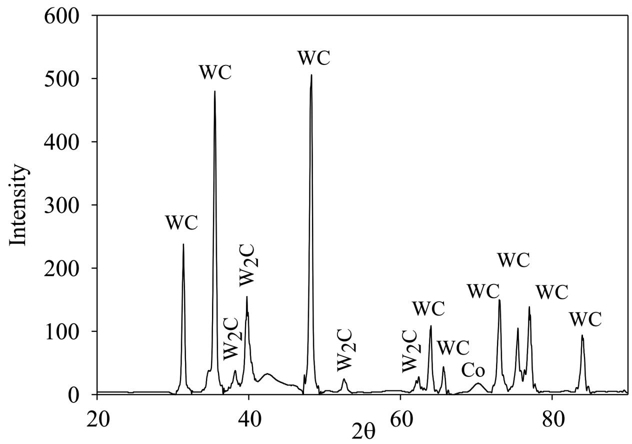

Fig. 4. XRD analysis of coated sample 5.

This indicates that the WC decarburized. During the spraying process, WC was dissolved into the binder and C was oxidized to CO or CO_2. During cooling, W precipitated as W_2C. The presence of Co peaks has been attributed to amorphous or nanostructured Co produced by splat quenching [12, 13].

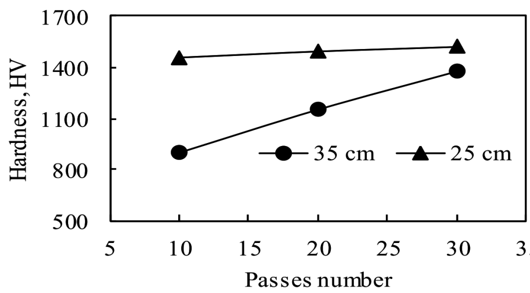

Fig. 5. The variation of hardness with nozzle distance and number of passes.

The microhardness value (Fig. 5) of the coatings increases with the increase of passes number because the porosity decreases generally [13] and the highest hardness is measured on sample 5 as 1524 HV, which is produced at 25 cm nozzle distance and 30 passes. In an open literature, WC–Co family coatings sprayed by HVOF process have hardness in the range of 900–1500 HV. The hardness of all coatings in the present study is in agreement with the reported literature [11, 14].

Generally, worn surfaces of all coatings are similar to each other and typical micrographs (sample 1 and sample 6 in Fig. 2) are given in Figs. 6 and 7. Here, Fig. 6 and Table III show the EDS analyses of sample 1, Fig. 7 and Table IV show the EDS analyses of sample 6 after the wear test. The dark grey areas in micrographs are W, Al, and O rich regions which indicate that some debris in the dark region may come from Al_2O_3 counter body. In addition, carbide pullout and microcracking is observed on the sliding surfaces and Ma et al. found similar phenomena [15].

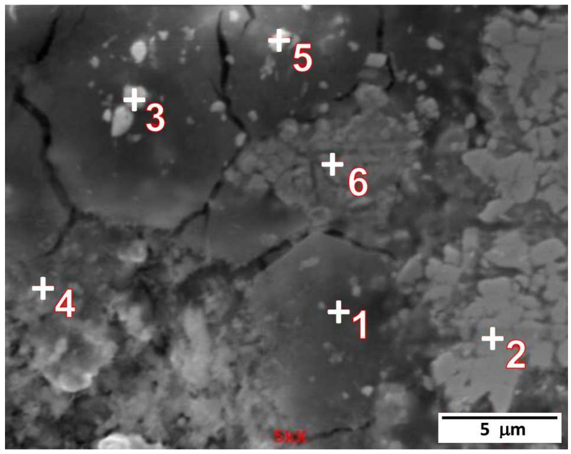

Fig. 6. EDS points of sample 1 worn surface.

TABLE III

EDS analysis [wt%] of sample 1 worn surface

No	C	O	Al	Cr	Co	W
1	–	28.33	17.64	5.59	9.65	38.79
2	4.23	–	–	0.31	1.42	94.04
3	3.24	13.94	5.31	0.32	1.38	75.81
4	–	19.21	17.34	6.21	15.19	42.05
5	–	34.44	24.48	2.49	6.59	32.00
6	2.02	–	–	1.61	3.62	92.75

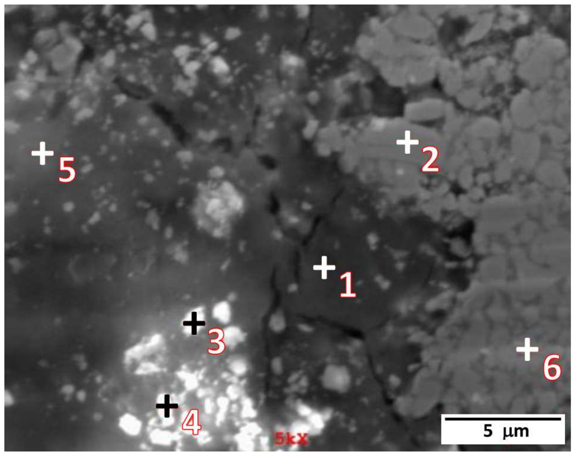

Fig. 7. EDS analysis of sample 6 worn surface.

TABLE IV

EDS analysis [wt.%] of sample 6 worn surface

No.	C	O	Al	Cr	Co	W
1	–	32.28	19.88	2.21	9.88	35.75
2	0.52	–	–	0.50	1.73	97.25
3	1.15	19.10	8.77	1.24	3.01	66.73
4	0.20	26.80	17.50	1.42	10.50	43.58
5	–	36.19	30.25	2.01	5.43	26.13
6	0.72	–	–	2.27	14.31	82.70

The friction coefficient of samples were given in Table V. Friction coefficient of coatings decreases with the increase of passes number and the decrease of nozzle distance similar to hardness. This result indicates that the higher hardness enables the smaller friction coefficient.

TABLE V

Friction coefficient at the different nozzle distance and the number of passes.

Number of passes	Nozzle distance [cm]	
	25	35
10	0.347	0.376
20	0.320	0.358
30	0.290	0.304

4. Conclusion

WC–Co–Cr cermet coatings were deposited onto stainless steel plates by HVOF spraying. Also friction and wear behaviors of coated samples at two different nozzle distances and three different passes are investigated by using the reciprocating slide tester by CSM test machine. The main conclusions can be drawn as follows.

1. WC10Co4Cr coatings by HVOF are very dense and have a good contact with substrate.
2. The coating layer thicknesses increase with decrease of nozzle distance and increase of passes numbers.
3. The highest hardness (1524 HV) is measured on sample 5 produced at 25 cm nozzle distance and 30 passes.
4. Friction coefficient of coatings decrease with the increase of passes number and the decrease of nozzle distance.

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