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Influence of Temperature on Tungsten Carbide Coating Sprayed by Different Spray Systems

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Tungsten carbide - cobalt hard coatings were deposited on steel substrates using a modified flame spray unit TopJet/2 and high velocity oxygen fuel MicroJet flame spraying system. The microstructure of coatings were analyzed by optical microscope LMA - 10. Porosity of coatings was determined by Scion Image computer program. X-ray diffraction has been performed to analyze the phase transformation of coating after spraying with different gas ratio and identify phase composition of wear products. The characteristics of the coatings made by the two spraying systems were evaluated under identical conditions. It was found that wear rate at room temperatures of the WC – 12 % Co coating sprayed by TopJet/2 and MicroJet systems are almost the same and differ in the range of 5 %. At temperatures over 300 ºC TopJet/2 sprayed coating showed greater wear resistance compared to the MicroJet sprayed coatings. Control specimens were made of tempered steel 45 (hardness 200HB).

Keywords: oxidation, flame spray, wear resistance, coatings.

1. INTRODUCTION

Wear at room and elevated temperatures is a serious problem for many machine components applied in aircraft, automobile and metallurgical industries. The use of thermally sprayed coatings to improve the wear resistance of components at relatively low cost has found widespread acceptance. The WC cermet sprayed coatings have outstanding properties such as high hardness and toughness, high rolling contact fatigue strength, good frictional characteristics, good wettability for aqueous agent, non picking or non adhesive property against foreign material, high thermal conductivity. Therefore they are extensively employed in these industrial fields [1 – 3].

The tungsten carbide cermets powder can be sprayed using different spray processes such as conventional flame spraying, plasma spraying, detonation spraying and HVOF spraying process. The coating properties are influenced not only by the properties of the used powders. Used spray process and spray parameters have significant influence, as well [4, 5].

Coatings deposited by high velocity oxygen fuel process (HVOF) have better wear resistant and adhesion with base material. This is mainly due to high velocity of sprayed particles. It ensures lower level of porosity in the coating in comparison with other processes such as conventional flame or plasma sprayed coatings, better cohesion in the coatings and less decarburization of WC related to the lower flame temperature. However due to the low flame temperatures HVOF has some restrictions, and cannot be used for spraying ceramic coatings in contrast to plasma and conventional flame spraying processes [6 – 8].

There is no comparative data regarding wear resistance at high temperatures of WC – 12 % Co coating sprayed by MicroJet and TopJet/2 spray systems.

In previous studies [9, 10] there were investigated tungsten carbide coating (WC – 12 % Co) sprayed by MicroJet system wear rate dependence on temperature, load and sliding speed.

The objective of our research was to: modify the gas flame gun TopJet/2 for spraying WC – 12 % Co powders; to investigate dependence of the porosity, chemical composition and amount of separate elements in WC – 12 % Co coating on spraying process and spraying parameters; to compare the wear resistance of coatings deposited by different spray systems at temperatures in range from 20 ºC up to 600 ºC; to identify the phase composition of wear products.

2. EXPERIMENTAL TECHNIQUE

A commercially available WC – 12 % Co spray powder with a size distribution of (53 + 10) μm was used in this study. Coatings were sprayed using a modified flame spray system – TopJet/2 and high velocity oxygen fuel system – MicroJet on the blasted cylindrical specimens of the 15 mm diameter and 15 mm length made of high speed steel (R6M5). The coating thickness was approximately 500 μm on diameter in the as – sprayed state, followed by grinding and polishing to approximately 300 μm for the sliding wear test. Control specimens were made of tempered steel 45 (hardness 200 HB).

Sliding wear test at room and elevated temperatures were performed on the wear machine. The detailed description of the used wear machine and wear conditions was described in our previous studies [11]. Wear rate was calculated from the mass loss during wear process using analytical balance BLP – 200 g. Sliding wear data reported in this study are the average of at least three runs.

For X-ray analysis dimensions of the samples were 8 × 8 × 20 mm. X-ray diffractograms for the starting powders, sprayed coatings, and worn surfaces were obtained by conventional Bragg-Brentano geometry ($\Theta - 2\Theta$ scans) on DRON-6 diffractometer using CuK_α radiation with generator current 20 mA and voltage 30 kV.

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The WC – 12 % Co coating phase composition was identified comparing experimentally obtained interplanar spacing *d* with the JCPDS data standards [12].

Quantitative analysis of our coating for chemical elements W and Co was performed by X-ray Fluorescence Spectrometer VRA-20. Rh K_{α} radiation produced by X-ray tube with current 26 mA and voltage 35 kV. The measurement time was 100 s. For each specimen and chemical element three measurements were performed. Errors of the measurements did not exceed 1 – 3 %.

Metallographical investigation was carried out using optical microscope LMA 10 with a camera YCH 15 and original software.

The porosity measurements were carried out analysing the cross – sections of the coating using computer image analysis program Scion Image.

TopJet/2 gas flame gun was modified for spraying cermet type coatings. Gas mixing parts and the nozzle were replaced to get supersonic speed and lower flame temperature. 95 % propane and 5 % of butane gas mixture (Agasol) was used instead of acetylene as the fuel gas. Powder feed channel to the gun combustion zone was made.

Operation principle of this gun is similar to the MicroJet one [13]. The gun consists of a mixing zone, combustion zone and the nozzle (Fig. 1). Fuel gas and oxygen are mixed and guided to the combustion zone where external igniter initiates the combustion. Combustion produces a hot high pressure flame which is forced down a nozzle increasing its velocity. The powders are fed into the combustion zone by a carrier gas (nitrogen). Powder feeder PF – 700 was used for powder dosage. Air was used as a coolant for nozzle, as well as a shroud for particles for increasing particles velocity.

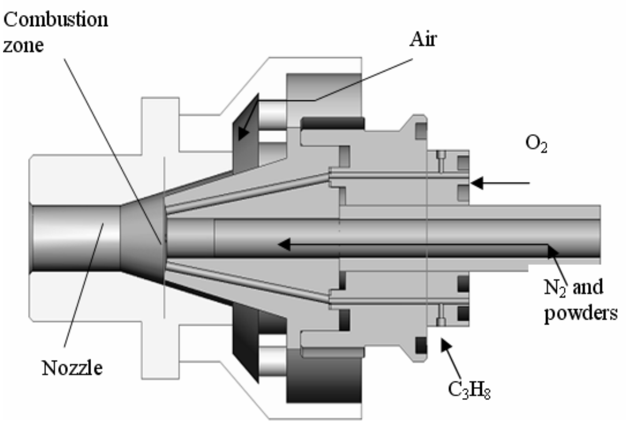


Fig. 1. Principal scheme of the TopJet/2 gun

Spray parameters were varied to investigate the influence of TopJet/2 system spray conditions on the coating properties. The spray parameters are shown in Table 1.

During the spraying specimen was cooled by air and maximum substrate temperature was 150° C.

Spray parameters of the Microjet system are shown in Table 1 [13].

Other spraying parameters in all cases were the same for both types of guns. Distance between the gun and specimens was equal 150 mm.

3. RESULTS AND DISCUSIONS

X-ray diffraction analysis has shown that after spraying no oxidation in the coating occurs. Used powders consisted of WC and Co phases. After spraying some transformations occurred and $W_6C_{2.5}$, W and amorphous binder phase of cobalt, tungsten and carbon appeared besides WC [14, 15]. It should be noted that phase composition of the coatings is not influenced by changing fuel gas and oxygen ratio.

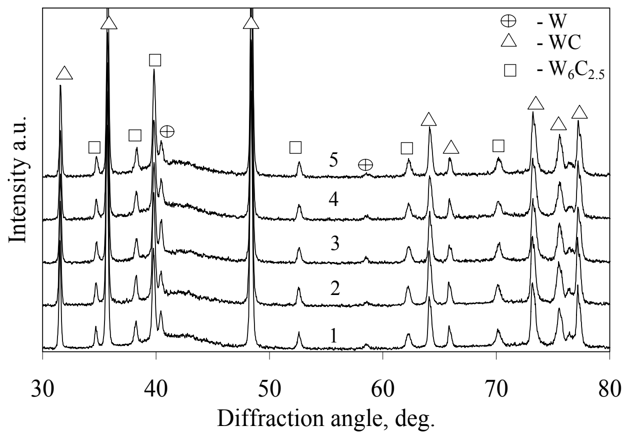


Fig. 2. X-ray diffractions patterns of WC – 12 % Co sprayed coating by TopJet/2 gun at different with different oxygen and fuel gas ratio (l/min): 1 – 14.45/131; 2 – 21/131; 3 – 21.7/131; 4 – 27.4/131; 5 – 31.6/131

The dependence of chemical elements W and Co in the coating on spraying parameters were determined using X-ray fluorescence spectrometry (XRFS) (Table 1). According to the results we can see that increase in fuel gas flux brings to the increase of concentration of W in the coatings deposited by both spray systems. It could be related to formation of the denser layer.

The cross-sections of WC – 12 % Co coatings deposited by MicroJet and TopJet/2 spray systems are shown in Fig. 3 and Fig. 4.

Table 1. Single chemical components content of WC – 12 % Co coating after spraying with Topjet/2 and MicroJet systems by using different gas ratio

Nr	Fuel gas, l/min	O_2, l/min	W, %	Co, %	(C and air) %	Pores, %
TopJet						
1	14.45	131	76.07	9.94	13.99	22.72
2	21.0	131	78.65	10.38	10.97	18.10
3	21.7	131	78.72	10.22	11.06	12.39
4	27.4	131	83.18	10.03	6.79	9.83
5	31.6	131	83.38	10.66	5.96	2.97
MicroJet						
6	22.5	51	73.63	11.46	14.91	7.48
7	22.5	142.6	74.78	11.87	13.35	4.43
8	25.6	142.6	76.62	12.00	11.38	0.78
9	29.5	142.6	80.37	12.00	7.63	0.40
10	33.3	142.6	80.15	12.00	7.75	0.42
11	36.4	142.6	79.55	12.00	7.92	0.16

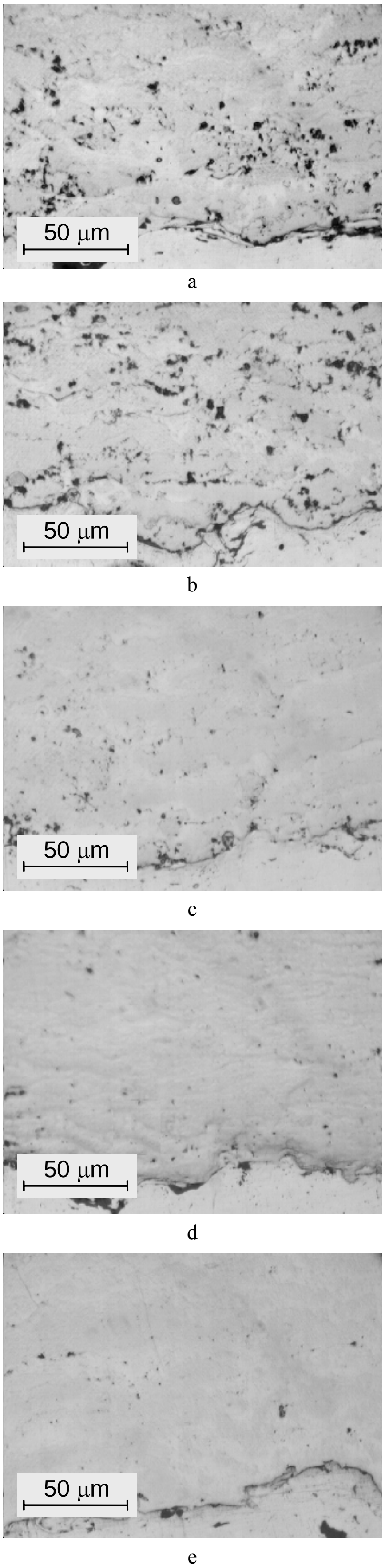


Fig. 3. Micrographs of cross section of WC – 12 % Co sprayed coatings by MicroJet system at different gas flux ratio (l/min): a – 22.5/51; b – 22.5/142.6; c – 25.6/142.6; d – 33.3/142.6; e – 36.4/142.6

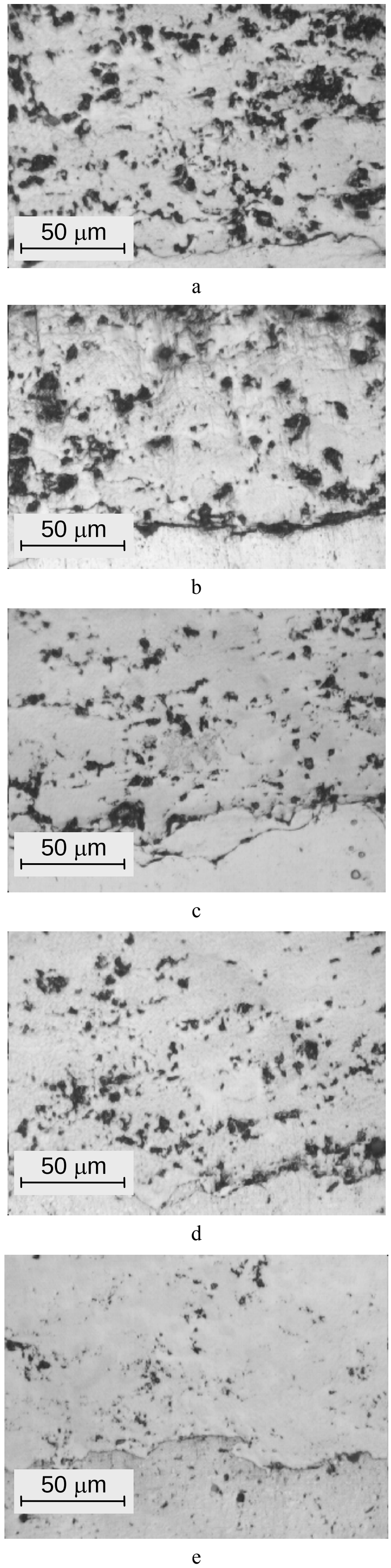


Fig. 4. Micrographs of cross section of WC – 12 % Co sprayed coatings by TopJet/2 system at different gas flux ratio (l/min): a – 14.45/131; b – 21/131; c – 21.7/131; d – 27.4/131; e – 31.6/131

From Fig. 3 it can be found that dense WC – 12 % Co coatings with MicroJet system can be sprayed at high fuel gas flow conditions when other conditions such as distance, temperature, nitrogen and powder flows are the same. In Figure 3a we can see, that for fuel gas flow 22.5 l/min and oxygen flow 51 l/min coatings have quite large size pores and porosity is 7.48 %. When oxygen flow increases up to 142.6 l/min (Fig. 3b) and fuel gas flow stays constant at 22.5 l/min, dimensions of pores in the coating are the same (porosity 4.43 %). After increasing fuel gas flow up to 25.6 l/min there is 0.78 % pores in the coating (Fig. 3c). When fuel gas flow is 29.5 l/min and 33.3 l/min porosity is 0.42 % (Fig. 3d). It is well seen that pores become smaller with fuel gas flow increase as compared with that deposited at low fuel gas flow conditions. Porosity is only 0.16 % when fuel gas flow reaches 36.4 l/min (Fig. 3e).

In Figure 4 we can see cross sections of WC – 12 % Co coating sprayed by TopJet/2 spray system. Comparing with coating sprayed by MicroJet we see that pores size are bigger and porosity reaches 22.72 % (when fuel gas flow is 14.45 l/min and oxygen 131 l/min). There is a relation between the porosity and fuel gas flow too.

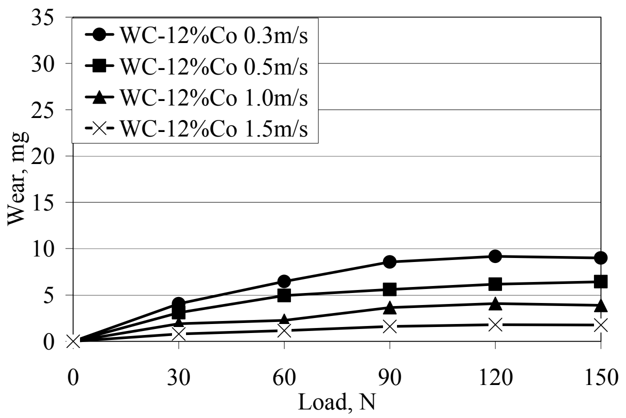
We can see that it is possible to change size of pores and quantity of them by changing gas ratio. This fact can be used for coatings working at different conditions: type of wear, pressure to coating, environment need different properties of coating.

Comparison of wear resistance of MicroJet sprayed WC – 12 % Co coating with wear resistance of TopJet/2 sprayed WC – 12 % Co coatings at various loads, sliding speeds measured at 20 ºC temperature is shown in Figure 5. As we can see wear rates are almost the same and differ in the range of 5 %.

The dependence of wear of WC – 12 % Co coating sprayed by different spray systems on temperature is presented in Figure 6.

At temperatures over 300 ºC TopJet/2 sprayed WC – 12 % Co coating showed better wear resistance than the Microjet sprayed WC – 12 % Co coating. (In all cases the load was the same (90 N)).

After the wear test at different temperatures X-ray diffraction measurements for counterface worn surfaces were performed (Fig. 7). Fe_2O_3 and WC wear products were found in the temperature range of 20 – 300 ºC. In the temperature range of 400 – 500 ºC $CoFe_2O_4$, $CoWO_4$, Fe_2O_3 were formed and $CoFe_2O_4$, $CoWO_4$, Fe_2O_3, Fe_7W_6 wear products – at the 600 ºC temperature.



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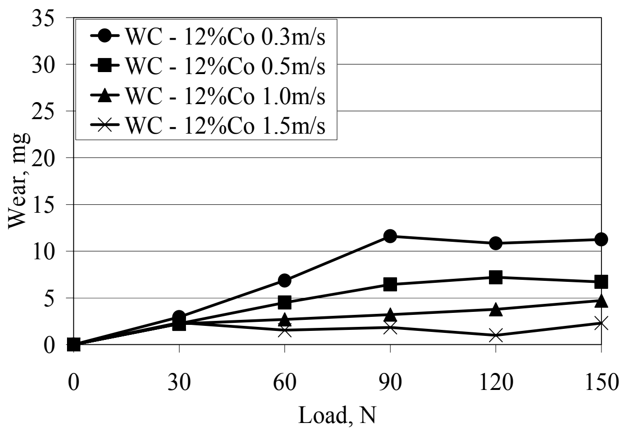
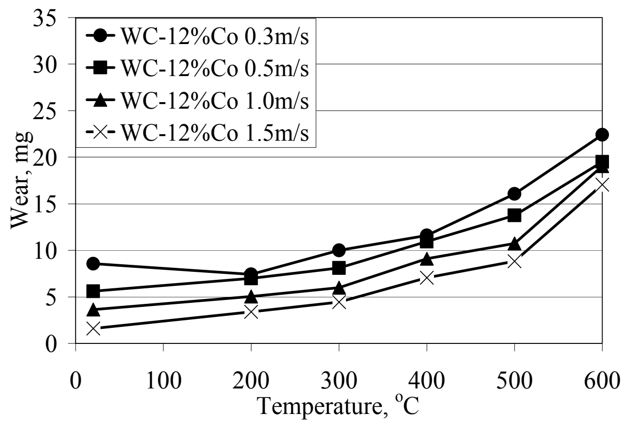


b

Fig. 5. Load influence on the wear rate of rotating specimen in pair with couterface (steel 45) when temperature is 20 ºC and sliding distance was 2000 m. a – WC – 12 % Co coating sprayed with TopJet/2 system; b – WC – 12 % Co coating sprayed with MicroJet system



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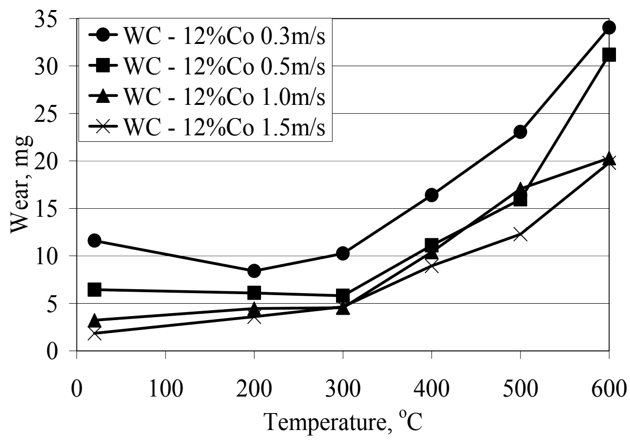

b

Fig. 6. The dependence of the wear rate of rotating specimen in pair with counterface (steel 45) on temperature influence when sliding distance was 2000 m. a – WC – 12 % Co coating sprayed with TopJet/2 system; b – WC – 12 % Co coating sprayed with MicroJet system

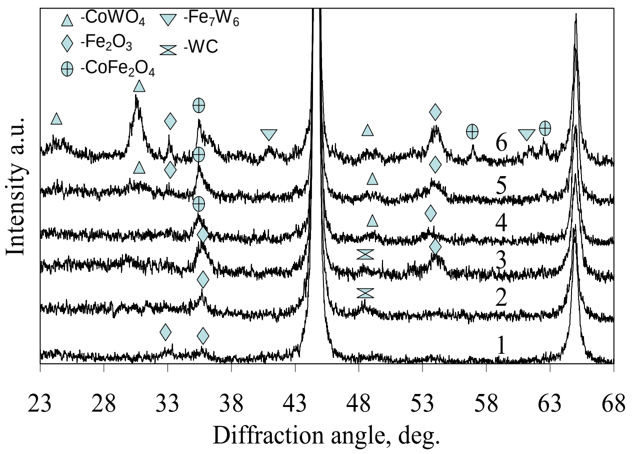

Fig. 7. X-ray diffractions pattern of WC – 12 % Co coating wear products at different temperatures 1 – 20 °C, 2 – 200 °C, 3 – 300 °C, 4 – 400 °C, 5 –500 °C, 6 – 600 °C

4. CONCLUSIONS

1. Wear rate of WC – 12 % Co coatings sprayed by MicroJet and TopJet/2 spray systems differ at room temperature less than by 5 %.
2. At temperatures over 300 °C wear resistance of WC – 12 % Co coating sprayed by TopJet/2 system is better.
3. X-ray analysis show that no oxide phases forms in the WC – 12 % Co coating sprayed by TopJet/2 system.
4. No phase changes occur in the coating deposited by TopJet/2 spray system by changing fuel gas and oxygen ratio at the spraying time.
5. An increment of fuel gas flow rate during the spraying process diminishes the porosity of sprayed coating.
6. WC – 12 % Co coating sprayed by MicroJet system was less porous than coating sprayed by TopJet/2 spray system.

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