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STUDY OF SELECTED PROPERTIES OF THERMALLY SPRAYED COATINGS CONTAINING WC AND WB HARD PARTICLES

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Abstract: The paper presents results of research of the essential characteristics of two kinds of advanced coatings applied by HVOF technology. One studied coating: WB-WC-Co (60-30-10%) contains two types of hard particles (WC and WB), the second coating is eco-friendly alternative to the previously used WC-based coatings, called "green carbides" with the composition WC-FeCrAl (85-15%). In green carbides coating the heavy metals (Co, Ni, NiCr) forming the binding matrix in conventional wear-resistant coatings are replaced by more environmentally friendly matrix based on FeCrAl alloy. On the coatings was carried out: metallographic analysis, measurement of thickness, micro-hardness, adhesion, resistance to thermal cyclic loading and adhesive wear resistance (pin-on-disk test). One thermal cycle consisted of heating the coatings to 600°C, dwell for 10 minutes, and subsequently cooling on the still air. The number of thermal cycles: 10. The base material was stainless steel AISI 316L, pretreatment prior to application of the coating: blasting with white corundum, application device JP-5000.

Key words: Coating, HVOF Technology, Adhesion, Friction Coefficient, Thermal Loading

1. INTRODUCTION

The components of production machines in technical practice are stressed by various operating conditions (transmitted forces, pressures, temperature, environment, etc.). By the influence of these diverse effects, in the majority of machines and their components stresses occurs, which causes unwanted damage of the surface (wear, deformation, corrosion, cracks, fractures etc.). To avoid substantial damage of surfaces of machinery components, there have been developed various methods of forming protective layers, resistant to operating conditions. Thermal spraying technology also belongs to such methods. Coatings formed using thermal spraying technology for its high hardness and wear resistance even at higher operating temperatures are often applied in many fields of industry, especially in automotive, aerospace, energy, engineering, manufacturing and mining industry.

Recently, just cermet coatings containing hard WC particles in metallic matrix applied using HVOF (High Velocity Oxygen Fuel) technology was seen as a less dangerous and more environmentally friendly alternative to hard chrome plating (Bolelli, 2012). Because the WC-based powders contain heavy metals such as Co and Ni (Brezinova et al., 2015; Aw and Tan, 2006; Żórawski, 2013; Sahraoui et al., 2010; Saha et al., 2011; Wood, 2010; Hulka et al., 2011; Hong et al., 2013a, b; Santana et al., 2008; Berget et al., 2007; Mati et al., 2007; Zavareh et al., 2015; Kaur et al., 2009), there is very strict logistics of powders used for coatings formation in the HVOF process. Currently, effort of materials scientists is focused on developing new powders, in which these elements in metallic matrix is eliminated and are replaced by other alloys. One of them is the powder WC-FeCrAl, called "green carbides".

The aim of the experiment was to evaluate the characteristics of the two types of coatings containing hard carbide particles in Co and also in Co-free matrix with respect to their tribological properties in atmosphere and in a corrosive environment (Brezinova et al., 2011, 2012, 2013).

2. MATERIALS AND METHODS

The base material for production of test samples was stainless steel AISI 316L. The test samples were of a cylindrical shape with a diameter of 25 mm and a length of 70 mm. The coatings were applied to the front area of the cylinder. Before powder spraying the base material was abrasive blast cleaned using white aluminum oxide with grain size of 0.56 mm, air pressure of 0.4 MPa, blasting angle of 90° and a blasting distance of 300 mm (Brezinova et al., 2015; Staia et al., 2000). The coating was applied by HVOF technology using TAFA JP-5000 spraying system under spraying parameters recommended by the powder manufacturer.

Powders used:

- WC-WB-Co (60/30/10), agglomerated and sintered, grain size +15/-45 µm, used for wear and corrosion protection in molten metal (for Zn bath rolls in Continuous Galvanizing Lines),
- WC-FeCrAl (85/15), agglomerated and sintered, grain size +15/-45 µm, wear resistant coating with Ni- and Co-free metallic binder, replacement for WC-Co or WC-Ni.

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The quality and thickness of coatings were assessed on metallographic sections using light and electron microscopy. The microhardness of the coatings was evaluated also on the metallographic sections (HV 0.1, 15 s)

The coatings were evaluated as-sprayed and after thermal cycles. One thermal cycle consisted of heating to 600 °C, dwell time of 10 min in furnace, followed by natural air cooling at room temperature. The number of cycles: 5 and 10.

Adhesion of coatings was determined by pull-off test (using 2K adhesive Loctite 9497) and wear resistance of coatings by pin-on-disc test (load 1.5 N, velocity 0.02 $m.s^{-1}$, duration of test 60 min, environment: atmosphere and immersion in 1 M NaCl solution, a static counterpart SiC ball).

3. RESULTS AND DISCUSSION

The thickness of the coatings was evaluated on several metallographic cross-sections. The cross-section of the coatings displayed by means of light microscopy (LM) is shown in Fig. 1. There the thickness of the coatings can be seen.

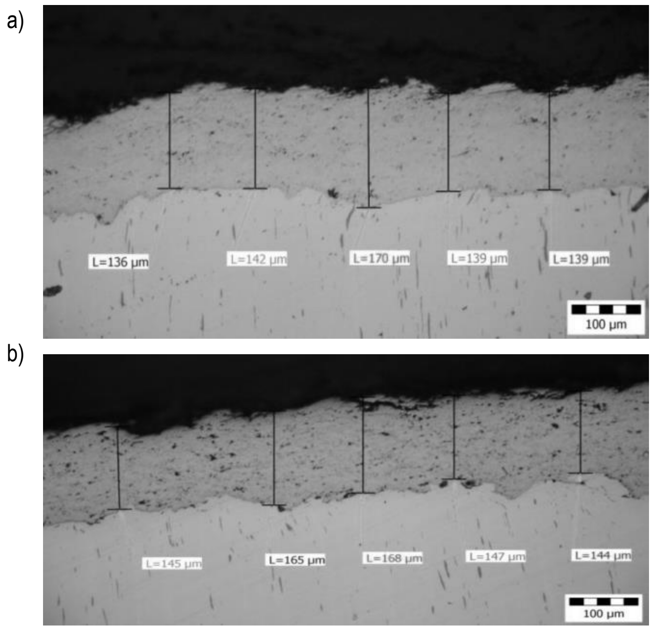

Fig. 1. Metallography section of the coatings: a) WC-WB-Co, b) WC-FeCrAl, LM

There is is a visible interface between the substrate and the coating in Fig. 1. The interface is broken, corresponding to profile of surface after grit blasting. The coating good fills all valleys in the surface, in the interface are not present any defects. The coatings are well anchored in surface irregularities. Average coatings thickness varies from 145 to 174 µm.

More detailed analyses of the structure of coatings were performed using SEM. The microstructure of the coating at magnification 5000× is showed in Fig. 2.

The coating WB-WC-Co consists of two types of hard particles (WC and WB) in soft binding Co matrix which ensures the coherence of carbides. The coating WC-FeCrAl contains hard particles of WC in a matrix based on FeCrAl alloy. Results of EDX analysis of chemical composition of coatings as-sprayed and also after thermal cycles are shown in Fig. 3.

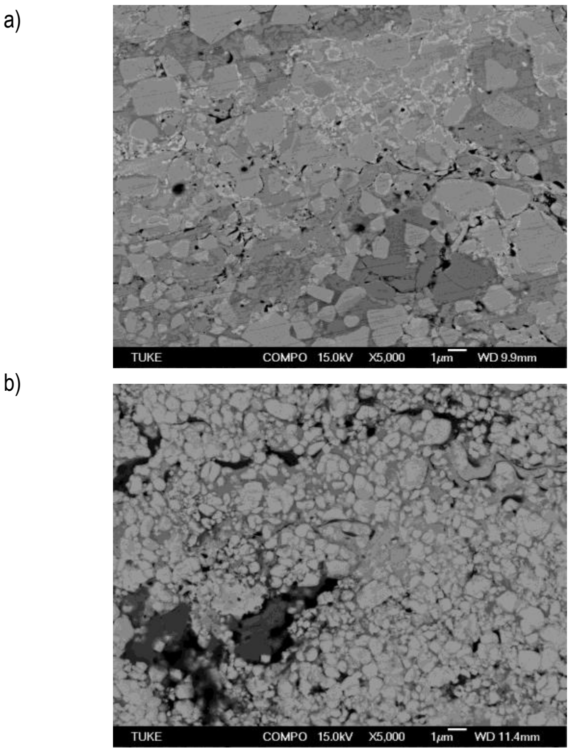

Fig. 2. SEM image of the coatings: a) WC-WB-Co, b) WC-FeCrA

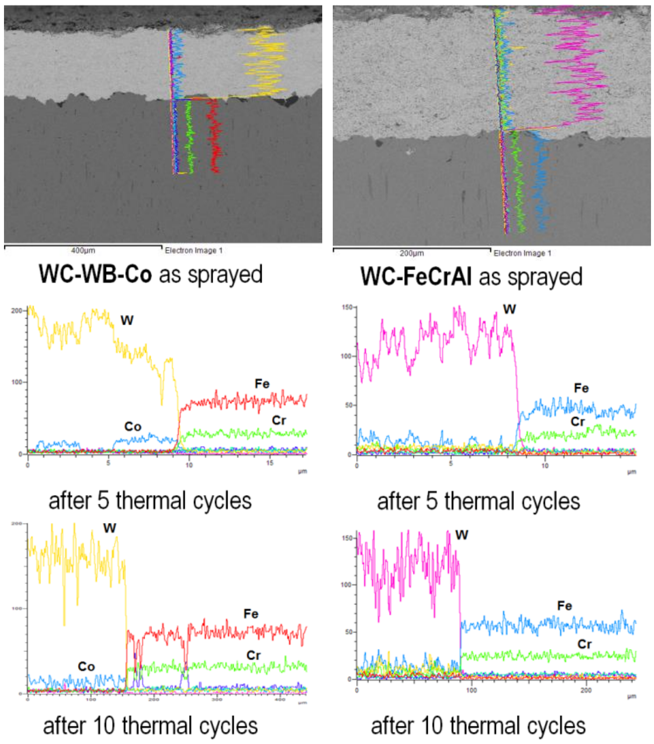

Fig. 3. EDX line scan composition profiles

Results showed that there are no changes in chemical composition of the coatings caused by thermal cyclic load.

The hardness of the coating WC-WB-Co was found between 1200 and 1300 HV 0.1 and hardness of coating WC-FeCrAl between 1000 and 1100 HV 0.1. Adhesion of both coatings as sprayed, or after thermal cyclic loading exceeded the cohesive strength of the adhesive used (>50 MPa). The results of determination of thickness, hardness, and adhesion of coatings are summarized in Tab. 1.

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Tab.1. Results of the tests

WC-WB-Co			
Number of thermal cycles	**0 (as sprayed)**	**5**	**10**
Thickness / µm	145	151	160
Hardness HV0.1	1303	1325	1229
Adhesion / MPa	>56	>51	>50
WC-FeCrAl			
Thickness / µm	165	157	174
Hardness HV0.1	1075	1050	1069
Adhesion / MPa	>50	>56	>54

Wear resistance of coatings as-sprayed and after the thermal cycles was evaluated by pin-on-disk test under dry friction conditions in the atmosphere and also immersed in the NaCl solution. The course of the friction coefficient during pin-on-disc test states Fig. 4.

a)
b)

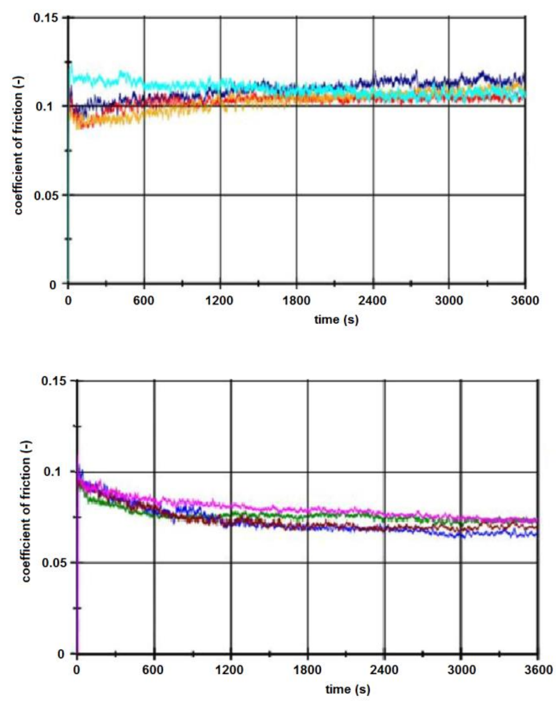

Fig. 4. Friction coefficient of the coatings after 5 and 10 thermal cycles in the atmosphere a) and in NaCl solution b)

Friction coefficient of the coatings in the atmosphere after the initial start-up became stabilized at a value of 0.1, and immersed in NaCl solution was stabilized below 0.1. During adhesive friction test in corrosive solution, the coefficient of friction stabilized at a lower value than in atmosphere.

The appearance of the coatings surface in wear track and out of wear track is shown in Fig. 5.

Weight loss of coatings after pin-on-disk test was minimal so could not be determined although the resolution of the balance was 10 to the negative 4th power [g], as confirmed also appearance of wear track. Surface of coatings in wear track and out of wear the track is almost identical, they are visible no signs of particles removed from coating material. Conversely, on the static counterpart was found visible loss of material, Fig. 6.

Material loss of each static counterpart is the same, judging by size of wear area - there are no differences between friction pairs as sprayed and after thermal cycling, as well as no differences between tests in the atmosphere and NaCl solution.

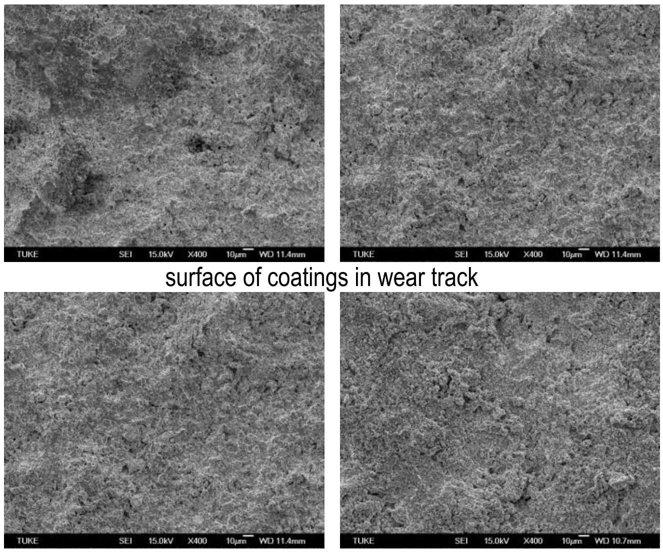

Fig. 5. Surface of the coatings in wear track and out of wear track

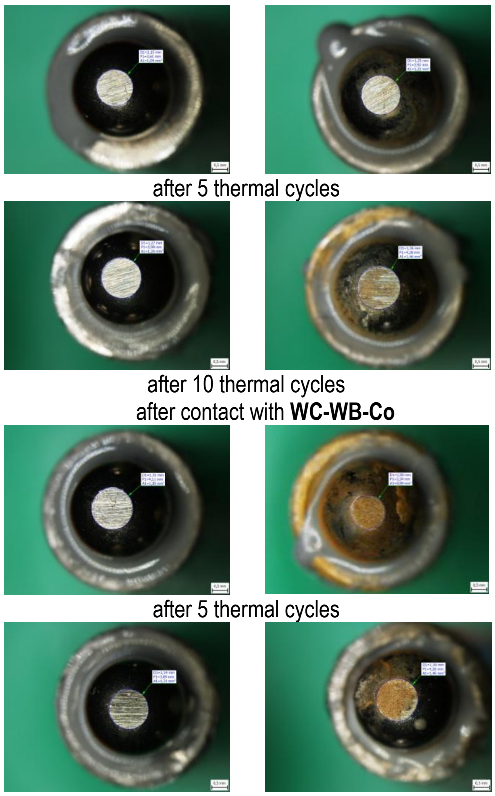

Fig. 6. Appearance of static balls

On the surface of static balls used in NaCl solution corrosion products are present.

4. RESULTS

Both coatings exhibited comparable properties as for thickness (140-170 μm), hardness (1300 and 1050 HV0.1), adhesion (> 50 MPa), and also in terms of adhesive wear resistance (non-measurable weight loss, low friction coefficient: 0.1 in the atmosphere and also in NaCl solution). It can be concluded that "green carbides" coating is environmentally more friendly replacement for coatings containing Co and Ni without reducing the performance of the coating.

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