JOURNAL OF OPTOELECTRONICS AND ADVANCED MATERIALS Vol. 17, No. 9-10, September – October 2015, p. 1425 - 1430

Substrate influence on the properties of thermally sprayed WC–CrC–Ni cermet coatings

V. A. ŞERBAN[a], I. D. UȚU[a,*], G. MĂRGINEAN[b]
[a]*University "Politehnica" Timisoara, Mechanical Engineering Faculty, Bv. Mihai Viteazu 1, 300222, Timisoara, Romania*
[b]*University of Applied Sciences Gelsenkirchen, Neidenburger Straße 43, D 45897 Gelsenkirchen ,Germany*

High velocity oxygen fuel (HVOF) technology needs in the last time to offer increased throughputs and feed powder utilization efficiencies. Heat input into the substrate component depends mainly on the spraying parameters and has to be rapidly built-up from the substrate material in order to achieve good mechanical, physical and chemical properties of the applied coatings. Therefore one should consider the influence of the thermal conductivity of the substrate on the properties of the sprayed coatings. In the frame of this research work, a WC-20CrC-7Ni feedstock powder was deposited using HVOF spraying method onto aluminum, brass and stainless steel. The importance of the substrate thermal conductivity was confirmed by the microstructural changes induced in the coatings during the deposition process. The coating properties such as microstructure, hardness and phase composition have been investigated by scanning electron microscopy (SEM), microhardness tests respectively X-ray diffraction (XRD). The corrosion behavior of the coatings was evaluated by potentiodynamic measurements using a three electrode open cell and the sliding wear resistance was determined using the pin-on-disk method. The obtained results demonstrate the importance of decarburation degree of the WC-phase on the corrosion and wear resistance of the coating.

(Received January 26, 2015; accepted September 9, 2015)

Keywords: Corrosion resistance, HVOF spraying, Cermet coatings, Sliding wear behavior

1. Introduction

Increasing engineering demands have led to special requirements for coatings and substrates so that they have to retain their mechanical strength and integrity during operation and must provide longer component lifetimes [1].

WC-CrC-Ni cermet coatings are widely used in order to improve the quality of components against various forms of wear (sliding, abrasion, erosion) and corrosion in different industrial applications whilst the substrate material provides support for any impact to which the component may be subjected. [1-4].

Usually these coatings are obtained by thermal spray processes. Because of the high velocities and low temperature developed during deposition compared with other techniques the high velocity oxygen fuel (HVOF) method is one of the most used processes to obtain dense cermet coatings with very high adhesive strength and microhardness as well as excellent properties regarding corrosion and wear resistance [5-8].

Many papers, in the literature, deal with the microstructural characterization of these coatings as a function of the deposition parameters, or with analysis of some technological properties such as wear or corrosion resistances, but few papers studied the behaviour caused by different cooling rates of the substrate after the coating process has been completed [9-11].

The purpose of this paper is to evaluate beside microstructure and phase composition also the corrosion and sliding wear resistance of HVOF sprayed WC-20CrC-7Ni coatings deposited on three different substrates, namely: aluminum, brass and stainless steel.

2. Materials and experimental procedures

The coating consisting of a fine sintered cermet powder 73%WC-20%CrC-7%Ni with a particle size range -10+2 μm was deposited onto three different substrates: aluminum, brass and stainless steel using a HVOF ID Cool Flow Gun. The powder and the HVOF equipment were manufactured by Thermico Company, Germany. Before deposition the specimens having square form of 50 mm side were degreased with acetone and grit blasted with corundum at 6 bars the blasting distance being 230 mm. The cermet coatings were sprayed (using a combustion mixture composed from oxygen, hydrogen and kerosene) under the same conditions; the spraying parameters were previously optimized in order to achieve a low porosity degree and a good interface with the substrate [12]. The spraying distance was kept to 125 mm. The coatings were cooled during deposition with compressed air. In all cases the coating thickness was about 200 μm and the roughness $R_a = 3.7$ μm.

The powder and the sprayed coatings were characterized by scanning electron microscopy (Philips XL-30 ESEM equipped with EDAX analyzer); the phase identification was made by X-ray diffraction technique (XRD-Philips X'Pert) using a Cu-K_α radiation.

The microhardness values of the coatings were measured with a micro-hardness tester Zwick ZHVμ-s with a 0.3 kgf load ($HV_{0.3}$).

The sliding wear behavior was determined by the pin-on-disk method using a tribometer from CJS Instruments Company. Coated samples surfaces were polished with diamond suspension in order to achieve a similar surface roughness (Ra). The wear rates were calculated using the measured values of the wear track depth as a result of the normal load applied to the ball (WC-Co with a 6 mm diameter). The operation conditions were: normal load 20 N, the relative velocity between the ball and surface v=20 cm/s, and the testing distance 1000 m (the trajectory was a circle with a radius of 5.4 mm).

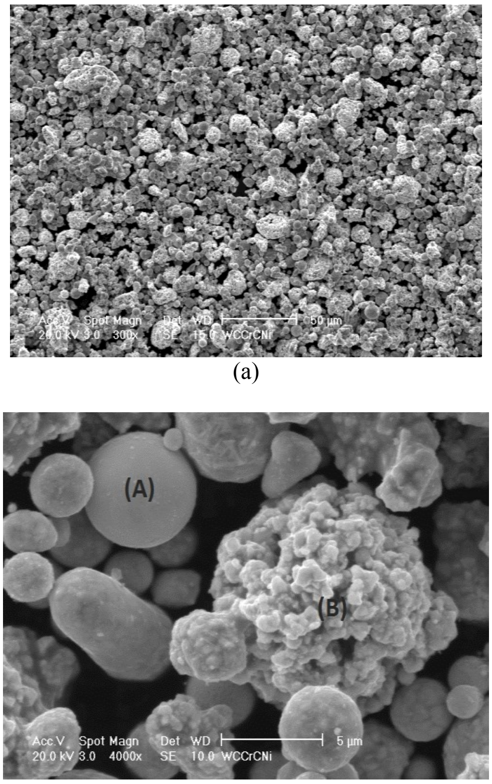
The corrosion behavior of the coatings was measured by cyclic voltammetry using a standard three-electrode cell, comprising a platinum auxiliary electrode and a satured calomel reference electrode.

Polarization curves were recorded in the positive direction starting at -1.5 V, with a scan rate of 5 mV/min, at room temperature in a 1M NaCl solution.

3. Results and discussion

3.1 Powder and coating characterization

Fig. 1 shows the morphology of WC-CrC-Ni powder at lower (Fig.1a) respectively at higher magnification (Fig. 1b). The WC-particles (A) have a different morphology in comparison with the CrC-particles which are aggregated by an abundant binder (B).

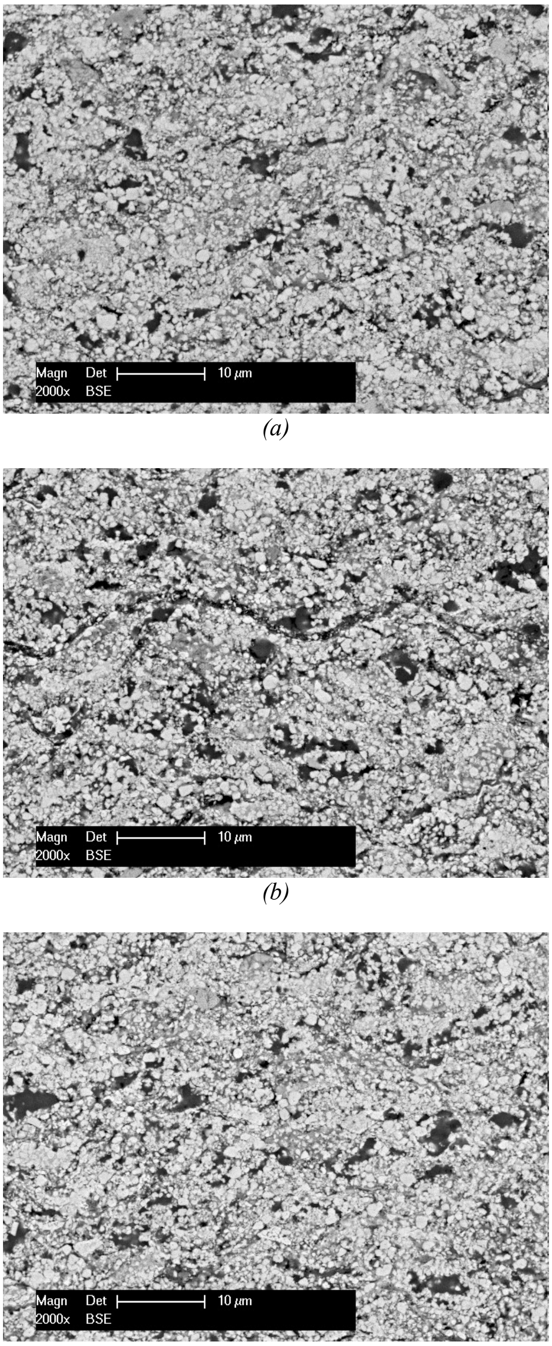


(a)

(b)

Fig. 1. Morphology of the WC CrC Ni powder

Fig. 2 presents the cross section SEM micrographs of the HVOF coatings sprayed onto the different substrates. All coatings have a lamellar, uniform and dense microstructure presenting a low degree of porosity, no microcracks or unmelted particles. A certain degree of internal oxidation can be noticed as well. It cannot be avoided because the spraying process was performed in atmosphere. The carbide particles are distributed heterogeneously within the coatings, giving rise to an heterogeneous microstructure [13].



(a)

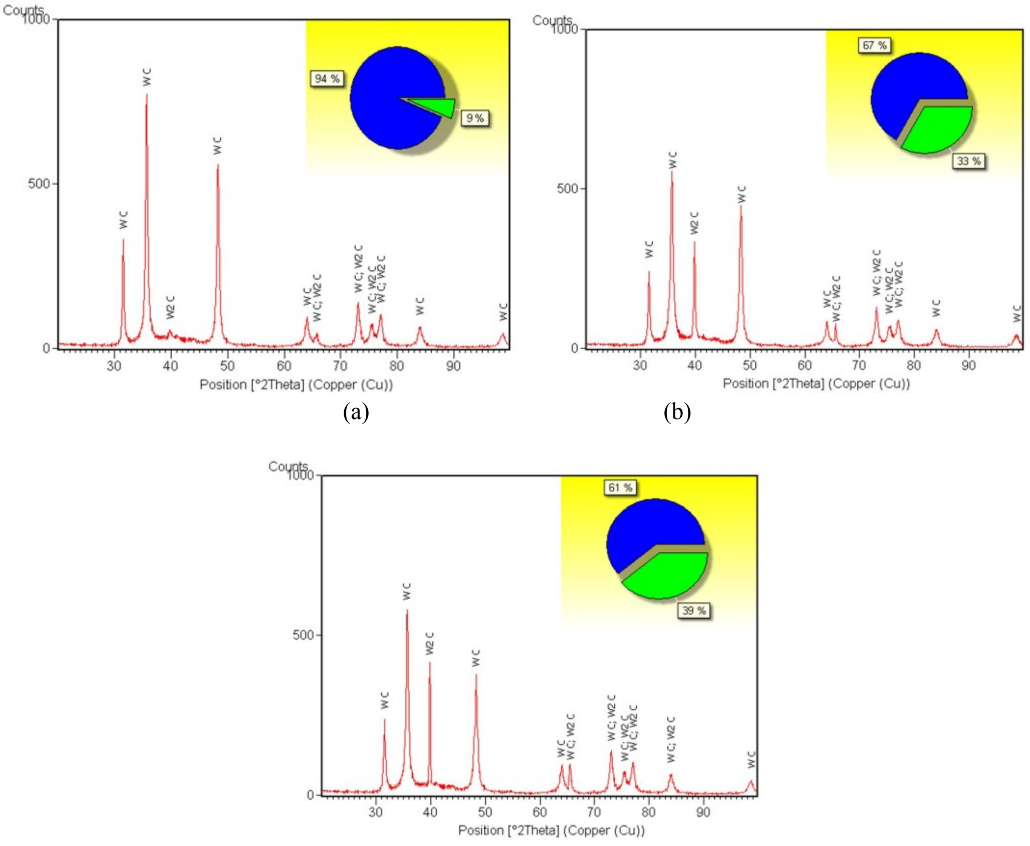
(b)

(c)

Fig. 2. Cross -section SEM micrographs of the WC-CrC-Ni coating on (a) aluminum, (b) brass, (c) stainless steel

Comparing the X-ray diffraction spectra of the WC-CrC-Ni coatings (Fig. 3), it can be noticed that in all cases the identified phases were WC and W_2C. Analyzing the results, a variation in the degree of decomposition was observed concerning the WC phase. Because the spraying conditions were the same the differences appeared due to specific heat/cooling capacity of the substrate. In case of the aluminum substrate, because the heat conduction loss is the highest comparing with that of the other two substrates, the degree of decomposition for the WC phase is the lowest (Fig. 3a). The coating deposited onto the stainless steel substrate exhibited the highest WC decarburation (Fig.3c) resulted in formation of W_2C.

These microstructural characteristics influenced the hardness of the coatings as well. Therefore, the obtained hardness values representing the average of 10 indentations were performed along the cross-section of the coatings (Table 1).



(a) (b)

(c)

Fig. 3. XRD diffraction patterns of the WC-CrC-Ni coating on (a) aluminum, (b) brass, (c) stainless steel

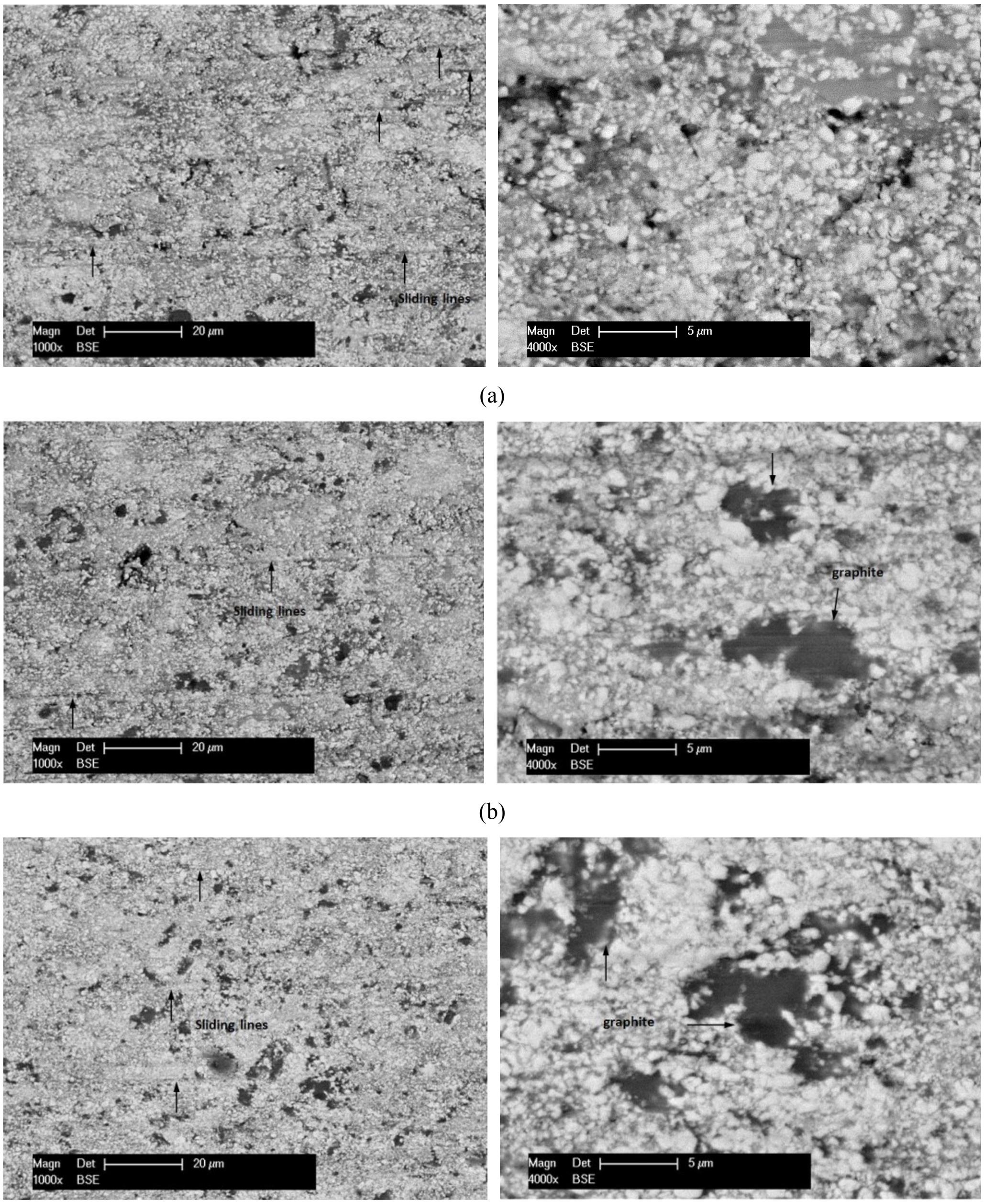
These results correlate very well with the degree of WC decomposition to a mixture of W_2C, WC and graphite upon cooling. Even than some literature reports about the properties of the W_2C-phase which is generally thought to be more brittle than WC and very hard [14], the obtained results from this experimental work demonstrated that the lower the decarburation degree, the higher the coating hardness (for ex. WC-CrC-Ni coating deposited on Al). The theoretical values for the W_2C-phase were determined considering the discrepancy between the hardness values depending on the indentation load used. In general, in the case of ceramic materials, the hardness is high at lower load and decreases when the load increases.

Table 1. Hardness values of the WC-CrC-Ni coating

Material	WC CrC Ni coating		
Substrate	Aluminum	Brass	Stainless steel
HV 0.3	997 ± 20	915 ± 20	894± 20

3.2 Sliding wear resistance of the coated specimens

The above noticed information correlates very well with the SEM micrographs of the WC CrC Ni wear tracks (Fig. 4) as well as with the calculated values for the specific wear rate (Table 2).



(a)

(b)

(c)

Fig. 4 SEM micrographs of the WC CrC Ni coating wear track on: (a) aluminum substrate, (b) brass substrate, (c) stainless steel substrate

Whereas the coatings deposited on brass respectively on stainless steel exhibited a similar behavior during the exposure to sliding wear, the cermet coating with lowest degree of decarburization (namely the one sprayed on aluminum substrate) has shown the highest value for the wear rate and according to this the worst sliding wear behavior.

This frictional behavior could be attributed to the specific phase composition of the investigated coatings especially concerning the ratio WC/W_2C which reflects automatically the generated graphitic phase which acts mainly as a lubricant during the sliding wear exposure [15].

SEM micrographs of the wear tracks at lower magnification (Fig.4, left side) revealed the existence of parallel sliding lines (see arrows) indicating a certain amount of abrasion wear [16]. This phenomenon is much pronounced in the case of the sample sprayed on aluminium (Fig. 4a) in comparison with other two samples (Fig. 4b and 4c) where the sliding wear is the predominant process due to the presence of the generated graphite (see the dark areas on the SEM micrographs at 4000 x in Fig. 4).

The results obtained from the microscopically investigations correlate very well with the determined wear rates (see Table 2). The higher the abrasion degree, the higher the value for the wear rate.

Table 2 Values of the wear rates for the WC CrC Ni coating

Material	WC CrC Ni coating		
Substrate	Aluminum	Brass	Stainless steel
Wear rate * 10^{-7} [mm^3/N/m]	36.25	24.95	23.02

3.3 Corrosion behavior of the coated specimens

It is well known that by cermet coatings the electrochemical corrosion behavior is in the first instance concentrated mainly on the binder phase [17]. The WC component plays also a dominant role in different potential regions [18]. Although the same WC CrC Ni powder has been used for all the depositions, due to the selection of different substrates some differences in phase composition and structure of the coatings were induced. These characteristics influenced furthermore the corrosion behavior in chloride medium [19].

The polarization curves of the tested materials recorded in a NaCl solution are presented in Fig. 5. The coating deposited onto the stainless steel substrate exhibited a slightly better corrosion in comparison with the other two coatings. This can be observed by comparing the values of the corrosion potential (E_{corr}) respectively that of the corrosion current density (i_{corr}) for all samples which are summarized in Table 3. The i_{corr} values for the coatings deposited on Al respectively on brass are similar whereas the value for coating deposited on steel was one order of magnification lower (6.125 μA/cm^2). A lower value for i_{corr} means a better corrosion behavior.

One may assume that the WC decarburation followed by several polymorphic modifications depending on the existing temperature, can produce a small alloying of the Ni binder phase with a certain amount of metallic wolfram.

$$2WC \rightarrow W_2C + C_{(graphite)};$$
$$W_2C \rightarrow WC + W_{(metallic)}$$

The differences recorded for the values of the E_{corr} are based on the coatings phase composition, as well. Based on the theory of the polarization measurements, one may observe that the potential of the coating deposited on Al is more cathodic than that of the other two samples. However the value of the recorded i_{corr} is more significant for the corrosion resistance of the material.

Table 3. Values of the measured corrosion potential and current density

WC CrC Ni coating	Electrochemical data	
	i_{corr} (μA/cm^2)	E_{corr} (mV)
Brass substrate	10.92	-557.8
Aluminim Substrate	13.99	-862.7
Stainless steel substrate	6.125	-720.1

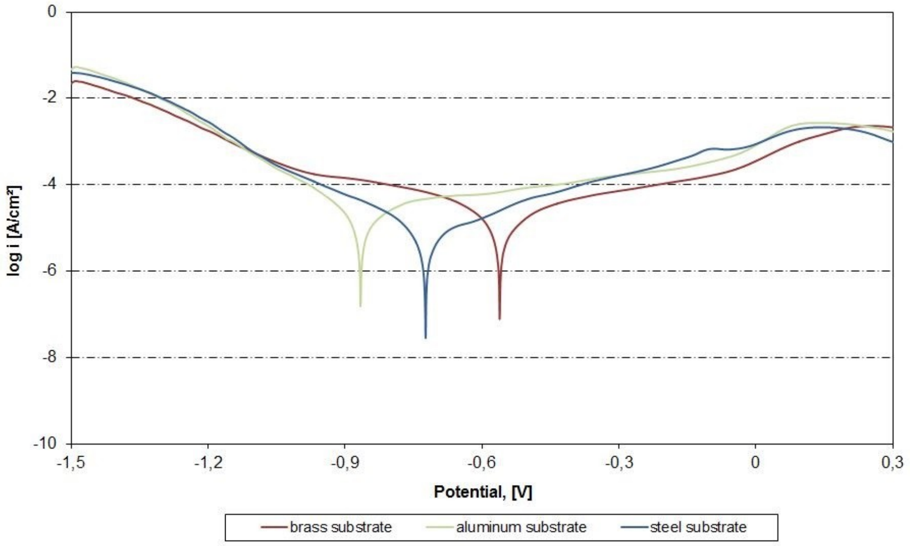


Fig. 5. Polarization curves of the cermet coatings sprayed on different substrates

4. Conclusions

The corrosion and sliding wear resistance of HVOF thermally sprayed WC CrC Ni coatings deposited onto three different substrates was investigated. Despite the fact that the chemical composition of the powder and the spraying process was the same, the properties of the obtained coatings were different.

Some microstructural changes appeared during the coating deposition because of the different specific heat/cooling capacity of the substrate. In case of the aluminum substrate the decarburation of WC was the lowest in comparison with that of the coatings sprayed on brass or on stainless steel. The surface hardness decreased with the increasement of decarburation degree, whereas the sliding wear behavior was improved due this phenomenon. It is difficult to define entirely the wear mechanism for the investigated WC CrC Ni coatings but based on the obtained results one may conclude that the phase composition may strongly influence the ratio between abrasion respectively sliding wear which directly influence the amount of total wear.

The corrosion resistance was also influenced by the decarburation degree. All the coatings exhibited good chemical properties in NaCl solution but the best electrochemical behavior was recorded by the coating deposited on stainless steel substrate.

Acknowledgments

This work was supported by a grant of the Ministry of National Education, CNCS – UEFISCDI, project number PN II-ID-PCE-2012-4-0104.

References

[1] G. Bolelli, L.-M. Berger, M. Bonetti, L. Lusvarghi, Wear, **309**(1-2) 96(2014).
[2] L.-M. Berger, S. Saaro, T. Naumann, M. Kašparova, F. Zahálka, Surf. Coat. Technol., **205**(4), 1080(2010).
[3] L.-M. Berger, S. Saaro, T. Naumann, M. Kašparova, F. Zahálka, J. Therm. Spray Technol. **17**(3), 395(2008).
[4] G.-L. Hou, H.-D. Zhou, Y.-L. An, G. Liu, J.-M. Chen, J. Chen, Surface & Coatings Technology. **206**, 82(2011).
[5] L. Zhao; M. Maurer, e.i., Wear, **257**, 41(2004).
[6] P.M Natishan, S.H. Lawrence, R.L Foster, J Lewis, B.D Sartwell, Surface and Coatings Technology, **130**(2–3), 218(2000).
[7] C. Verdon, A. Karimi, J.-L. Martin, Materials Science and Engineering A, **246**, 11(1998).
[8] L.-M. Berger, Coatings by Thermal Spray, in: V.K. Sarin, D. Mari, L. Llanes, C.E. Nebel (Eds.), Comprehensive Hard Materials - **1**, 471 (2014), Elsevier.
[9] L. Fedrizzi, L. Valentinelli, S. Rossi, S. Segna, Corrosion Science, **49**, 2781(2007).
[10] P.H. Shipway, D.G. McCartney, T Sudaprasert, Wear, **259**(7), 820(2005).
[11] O.P. Oladijo, N. Sacks, L.A. Cornish, A.M. Venter, Int. Journal of Refractory Metals and Hard Materials, **35**, 288(2012)
[12] I.D. Utu, I. Hulka, V.A. Serban, Materials Testing **55**, 47(2013)
[13] Z. Marcano, J. Lesage, D. Chicot, G. Mesamacque, E.S. Puchi-Cabrera, M.H. Staia, Surface &Coatings Technology, **202** 4406(2008).
[14] H. Taimatsu, S. Sugiyama, Y. Kodaira, Materials Transactions, **49**(6), 1256(2008).
[15] S.Z. Hao, Y. Zhang, Y. Xu, N. Gey, T. Grosdidier, C. Dong, Applied Surface Science, **285P**, 552 (2013).
[16] L. Thakur, N. Arora, R. Jayaganthan, R. Sood, Applied Surface Science, **258**, 1225(2011).
[17] J. M. Perry, An. Neville, T. Hodgkiess, Journal of Thermal Spray Technology, **11**(4), 536(2002).
[18] F.J.J. Kellner, H. Hildebrand, S. Virtanen, Int. Journal of Refractory & Hard Materials **27**, 806(2009).
[19] M. A. Domingues-Crespo, E. Onofre-Bustamant, A. M. Torres-Huerta, F.J. Rodriguez-Gomez, J. Mex. Soc., **52**(4), 235(2008).

---

[*] Corresponding author: dragos.utu@upt.ro