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Structure and Properties of the Hardmetal Coatings Cr3C2-25NiCr Formed by a Multi-chamber Detonation Sprayer

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Abstract. The hardmetal Cr3C2-25NiCr (180-220 µm thick) coatings have been produced on a steel substrate by a multi-chamber detonation sprayer (MCDS). The characteristic feature of MCDS is that the powder is accelerated by using combustion products that are formed in MCDS chambers and are converged before entering the nozzle, where they interact with the two-phase gas-powder cloud. The microstructures and properties of the hardmetal coatings were examined with the use of optical microscopy, scanning electron microscopy, X-ray phase analysis, and a Vickers hardness tester with a 300 g test load. Wear tests were carried out using a computer controlled pin-on-disc type tribometer. It was established that MCDS has provided the conditions for formation of a dense hardmetal Cr3C2-25NiCr (180-220 µm thick) coatings with a porosity of less than 0.02%, microhardness 540±210 HV0.3 and a specific wear rate of 9.08·10-5 mm3(m·N)-1.

1 Introduction

The materials used as coatings must ensure an effective protection against oxidation as well as have a high thermal conductivity (heat-exchangers) in order to provide good service behaviour and an effective and economical maintenance layout [1]. Thermally sprayed coatings based on hard carbides embedded in a metallic matrix (Cr3C2-NiCr system) have been used for corrosion and wear resistant applications [2,3]. Carbides based cermets coatings are widely used against wear and corrosion in gas and oil industries. Their wear resistance is three to five times that of electroplated chromium, and their manufacturing costs are low [4]. In thermal spray technology, Cr3C2-NiCr cermet coatings have been extensively used to mitigate abrasive and erosive wear at high temperatures up to 850 °C [5]. These Cr3C2-NiCr cermet coatings are deposited by plasma spray [6], cold-spray [7], high velocity processes namely high velocity oxy-fuel (HVOF) [8] and detonation gun spray (DS) processes [9].

The aim of this paper is to investigate the microstructure and properties of Cr3C2-25NiCr powder coatings were obtained on steel substrate by a new multi-chamber detonation sprayer which allows achieving the powder velocity of 1400 m/s.

2 Experimental Procedure

The Cr3C2-25NiCr powder (POLEMA JSC, Russia) (d(0.1): 35.57 µm, d(0.5): 78.34 µm, d(0.9): 141.72 µm) was used as the starting material to deposit a dense layer on a plate with dimensions of 30 x 30 x 5 (mm) of the steel substrate. The particle size was measured by laser diffractometry Analysette 22 NanoTec. The composite powder was prepared by solid state mixing route (Cr3C2: Ni20Cr wt ratio = 75:25) (Fig. 1). The phase analysis of Cr3C2-25NiCr powder results are shown in Table 1. Flat specimens of steel (Table 1) were used as substrates, and they were sandblasted by an alumina grits 25A F360 prior to spraying. The specimens were transversally cut by spark erosion, mechanically polished and prepared by standard metallographic sample preparation sectioning, mounting and polishing methods. This involved grinding with abrasive SiC paper (200, 500, 800 and 1,000 grades). The specimens were then polished using 6, 3 and 1-micron diamond polishes on a lubricated cloth.

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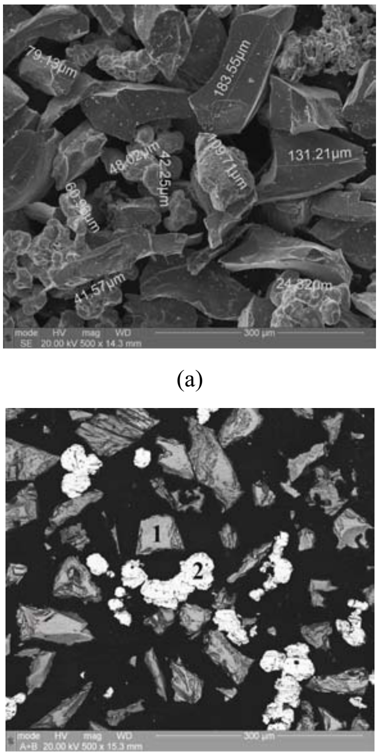

(a)

(b)

Fig. 1. The Cr_3C_2-25NiCr powder SEM image (Quanta 200 3D); 1 - Cr_3C_2, 2 – Ni20Cr (back-scattered electron mode)

In the present study, a multi chamber, vertically mounted, detonation sprayer (MCDS) [10] with a barrel length of 300 mm was employed to deposit the Cr3C2-25NiCr coatings upon a steel substrate. The characteristic feature of MCDS is that the powder is accelerated by using the combustion products that are formed in the MCDS chambers and are converged before entering the barrel, where they interact with the two-phase gas-powder cloud. A standard powder feeder from Metco Company is used to feed powder to the barrel.

The Cr3C2-25NiCr coatings were deposited with a frequency of 20 Hz. The movement speed was 2000 mm/min, the distance from the exit section of the barrel to the treated plate was 55 mm. A barrel with a throat diameter of 18 mm was adopted. The flow rate of the fuel mixture components (m3/h) was oxygen (3.13*/3.25**), propane 30%+butane 70% 0.71*/0.75**) and air (1.56*/1.39**) (*cylindrical form combustion chamber, **combustion chamber in the form of a disk). The powder feed rate was 1900 g/h.

The microstructure and elemental composition of the powder and coatings were determined by using the scanning electronic microscopes (SEM) Quanta 200 3D. Porosity was determined by the metallographic method with elements of the qualitative and quantitative analysis of the geometry of the pores by using optical inverted microscope Olympus GX51. A local phase analysis was conducted by using X-ray powder diffractometer Rigaku Ultima IV. Crystalline phases were identified using the ICCD PDF-2 (2008) powder diffraction database. Microhardness was measured on cross-sections of the samples of the coatings with an automatic DM-8B (Affri) microhardness tester using a Vickers's test with a 300 g test load, the distance between the indents was 20 µm. The tribological evaluations of the coated substrates under dry conditions were performed using a ball on disc tribometer CSM Instruments according to ASTM wear testing standard G-99. The total wear volume was calculated by measuring the track cross-sectional area with a stylus profilometer (Taylor-Hobson) at ten different locations along the wear track. The ASTM G-99 standard determines the amount of wear by measuring the appropriate linear dimensions of both specimens (ball and disk) before and after the test [11]. On average, 10 tests were used as an indicator of the coating hardness and wear resistance. The all obtained samples are characterized by almost the same microstructures and properties. Arbitrary selected data are presented in the paper.

Table 1. The chemical composition, phase composition of powder and coatings, and mechanical features of Cr_3C_2-25NiCr coatings

	Powder		Coating	Steel
	75%Cr_3C_2	25%Ni20Cr		
Chemical composition, all in wt pct	Cr-85.5 C-13	Ni-78.38 Cr-20.9 Ca-0.02 Si-0.10 Mn-0.05 Ti-0.07 Fe-0.30 C-0.02 O-0.07 S-0.02	Ni-78.38 Cr-46.08 Si-0.40 Ti-0.12 Fe-0.63 C-5.97 O-6.43 S-0.20	Cr-17.5 Ni-9.4 C-0.06 Si-0.5 Mn-1.2 P-0.02 S-0.02 Ti-0.48
Identified major phases	$CrNi_3$ Cr_3C_2 C		$Cr_{1.12}Ni_{2.88}$ Cr_7Ni_3 Cr_7C_3	-
Microhardness, [$HV_{0.3}$]	-		540±210	205±12
Specific wear rate* ($x10^{-5}$) [$mm^3(m\cdot N)^{-1}$]	-		9.08	35.99**
*counterbody (a 6 mm in diameter aluminum oxide (Al_2O_3) ball), 10 N normal load, 0.15 ms^{-1} sliding speed, a total sliding distance of 500 m				
**test was stopped on a passing friction path of 300 m				
Surface roughness (polished surface) $R_a = 3.04 \pm 0.01$ [µm]				

3 Results and Discussion

The thickness of deposited coatings ranged about 80-120 μm. As shown by examinations of microstructure of a transverse section of a coated sample (Fig. 2), the Cr3C2-25NiCr coating is uniform and dense, and has a good adhesion to the substrate. The bulk of the coating material is deformed and closely packed. It was clearly recognized that the coatings consisted of lamellae elongated in the direction parallel to coating surface. All coatings present a dense microstructure with a few pores visible (the porosity less than 0.02%). A close examination of the microstructure reveals that carbide particles were distributed in the coating evenly (Fig. 2). The interface between the coating and the substrate had no visible macro defects.

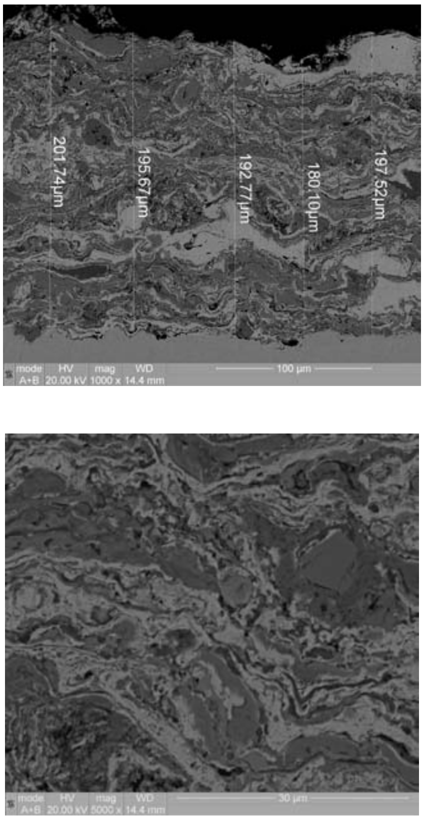

Fig. 2. SEM cross section images (back-scattered electron mode) of the Cr$_3$C$_2$-25NiCr coating

The measured hardness values are reported in Table 1. A wide range of hardness values in obtained coatings is caused by their different phase composition. This hardness range is, as expected, slightly lower than previously reported hardness values for HVOF-sprayed coatings (870-950 HV0.3) [8], cold-sprayed coatings (843 HV0.3) [7] but is surprisingly similar to those reported for coatings produced using plasma (561 HV0.3) [6] or D-gun (742 HV0.3) processes [9].

The results of XRD analysis of coatings are reported in Table 1. In the Cr3C2-25NiCr coating, the carbide Cr7C3 was present. It is generally considered that this carbide is formed through decarburization of Cr3C2 carbide.

A specific wear rate of Cr3C2-25NiCr coatings was as low as 9.08·10-5 mm3(m·N)-1. This is much less than a specific wear rate of steel (Table 1). The main reason that the wear resistance of the coated samples was much better than that of the uncoated is that there exist many types of carbide and few oxides in the dense coating, with good bonding to the substrate.

4 Summary

The Cr3C2-25NiCr coating on the flat specimens of steel was produced by a multi-chamber detonation sprayer. A dense layer at lamellas and deformed particles with porosity of less than 0.02 % was formed on the sample surface. The Cr3C2-25NiCr coating has a hardness of 540±210 HV0.3 and specific wear rate of 9.08·10-5 mm3(m·N)-1. The results of this work open up new prospects for the further elaboration of new technologies for making Cr3C2-25NiCr coating that can enhance the properties of steel.

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References

1. E. Fernandez, J.R. Garcıa, J.M. Cuetos, V. Higuera: Surf. Coat. Technol. Vol. 195 (2005), p. 1.
2. J. Mateos, J.M. Cuetos, R. Vijande, E. Fernandez: Tribol. Int. Vol. 34(5) (2001), p. 345.
3. J.M. Guilemany, J. Ferna´ndez, J. Delgado, A.V. Benedetti, F. Climent: Surf. Coat. Technol. Vol. 153 (2002), p. 107.
4. F. Rastegar, D.E. Richardson: Surf. Coat. Technol. Vol. 90 (1997), p. 156.
5. W. Tillmann, E. Vogli, I. Baumann, G. Kopp, C. Weihs: J. Therm. Spray Technol. Vol. 19(1-2) (2010), p. 392.
6. J. Mateos, J.M. Cuetos, R. Vijande, E. Ferna´ndez: Trib. Int. Vol. 34 (2001), p. 345.

7. D.E. Wolfe, T.J. Eden, J.K. Potter, AP. Jaroh: J. Therm. Spray Technol. Vol. 15(3) (2006), p. 400.

8. T.S. Sidhu, S. Prakash, R.D. Agrawal, Surf. Coat. Technol. Vol. 201 (2006) p. 792.

9. Y. Wang: Wear. Vol. 161 (1993), p. 69.

10. N. Vasilik, N. Tyurin, O. Kolisnichenko, Method for gas-dynamic detonating speedup of powders and device for its implementation, RU Patent 2506341, 2012.

11. Standard test method for wear testing with a Pin-on-Disk apparatus, ASTM G99-05(2010), Book of ASTM Standards, American Soc. for Metals, (2010).