INFLUENCE OF THE DEPOSITION PARAMETERS ON MICROSTRUCTURE AND PROPERTIES OF HVOF SPRAYED WC-CRC-NI COATING

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Abstract

This paper investigates the influence of thermal spray parameters of the high-velocity oxygen fuel (HVOF) process on the properties of cermet coatings prepared from commercially available Amperit 551 WC-CrC-Ni powder. Three different processing parameters were applied to optimize the production process with the aim to achieve preeminent mechanical properties and fully dense material without microstructural defects. The deposition was carried out by a GLC5 gun. The velocity and temperature of powder particles in the spray stream were monitored by Accuraspray Tecnar diagnostic tool. The quality of deposited coatings was analyzed by means of light microscopy, scanning electron microscopy, and X-ray diffraction. The chemical composition of the used powder and sprayed WC-CrC-Ni coating was determined by energy dispersive spectroscopy. It was found that the spray parameters have a negligible effect on the resulting microstructure and phase composition of the coating. However, the porosity and surface roughness were significantly affected by the variation in process parameters. To assess the basic mechanical properties of HVOF sprayed coating instrumented Vickers hardness measurements were utilized. The coating hardness reached mean values over 1400 HV 0.1 and the indentation modulus varied from 152-279 GPa.

Keywords: HVOF, WC-CrC-Ni, microhardness

1. INTRODUCTION

High-velocity oxygen fuel (HVOF) is a thermal spray process based on the continuous combustion of oxygen with gas or liquid fuel. The thermal energy produced in the process causes an expansion of the gas mixture and leads to the creation of a hot supersonic gas stream which carries feedstock powder particles to the substrate surface. Feedstock powders are then deposited onto a substrate in a semi-molten condition or a fully solid state [1]. Deposition parameters play a crucial role in spray process. There are plenty of possible variations of parameters in the HVOF process, which affect the microstructure, surface roughness, porosity as well as the resulting mechanical properties. Some of them are connected with the design of a nozzle as fuel or oxygen flow, some of them are connected directly with the state of the spray stream, e.g., velocity and temperature of particles and there are also parameters connected with the substrate [2]. The most influential parameters are the velocity and temperature of the particles. Both can be measured with diagnostic tools such as Accuraspray Tecnar, Spraywatch, etc. [3]. Involvement of these tools has a great impact not only on the optimization of mechanical and tribological properties of coatings, but also on improving the quality of deposition by lowering the amount of microstructural defects: pores, cracks etc.

Cermet materials are often categorized in the group of metal matrix composites. Due to their superior hardness, wear and corrosion resistance, and an also outstanding fracture toughness, cermets are commonly used for contact surfaces of drilling machines and wear parts of measurement tools. Cermets are usually composed of two main constituents. The first one is matrix consisting of ductile elements (alloys) such as Co, Ni and Fe. The second one is a reinforcing phase consisting of hard and brittle components such as carbides, nitrides or carbonitrides [4, 5]. The most commonly used cermets are based on WC reinforcing phase and Co matrix. Recent research has been focused on the replacement of Co by Ni. Additionally, Cr_3C_2 can be added to increase corrosion resistance [6, 7].

2. EXPERIMENTAL PROCEDURE

2.1. Materials and coating deposition

The powder used for deposition was commercially available agglomerated and sintered (s&a) 73WC-20CrC-7Ni powder Amperit 551.074 (15-45 µm) manufactured by Höganäs. The coatings were prepared by HVOF spraying using a GLC5 gun from GTV and installed on a six-axis IRB 2600 Robot. Three different conditions of spraying were used. In **Table 1**, these parameters are displayed also with the in-flight temperature and velocity of powder particles recorded at the moment of impact onto the substrate surface. For measuring velocity and temperature, the Accuraspray G3C system from Tecnar was utilized. Variations of these parameters were primarily in fuel flow (ethylene) and oxygen flow. Austenitic steel AISI304 in a form of cylindrical coupons (Ø30 mm x 10 mm) was used as a substrate material. Before the deposition, austenitic steel coupons were grit blasted by Al_2O_3.

Table 1 HVOF deposition parameters

Coating designation	Low parameters (LP)	Medium parameters (MP)	High parameters (HP)
Ethylene (slpm)	48	96	96
Oxygen (slpm)	96	126	250
Spraying distance (mm)	200	200	200
Particle velocity (m/s)	338	372	455
Particle temperature (°C)	1810	1708	1814

2.2. Characterization Methods

Metallographically prepared cross-sections of coated coupons were observed by several methods including light microscopy (LM) Olympus DSX1000, scanning electron microscopy (SEM) - LYRA TESCAN 3 equipped with energy dispersive spectrometer (EDS) Oxford X-Max80. Coating thickness was measured from images acquired by LM. At least five SEM images were analysed by Olympus Stream software to determine the porosity of coatings.

X-ray powder diffraction (XRPD) was used to analyse the phase composition of powder form and phase evolution in the coated layer. The coatings were measured on the surface area. The diffraction was measured in 2θ range of 30-80° with step size set to ~0.05°. Measurements were carried out in reflection mode using Bragg-Brentano beam geometry on X-ray powder diffractometer Empyrean (PanAnalytical) with Co Kα X-ray source

Vickers microhardness HV 0.1, elastic indentation modulus (EIT) and indentation hardness (HIT) were measured on the metallographic sections using a universal testing machine Roell-Zwick (ZHU 0.2) at a load of 0.98 N and with 20 indentations per specimen. This load was used to prevent the coating from cracking. Moreover, HV 0.3 instrumented hardness measurement was performed on the coating with the lowest value of porosity to compare acquired values with the results of other scientific articles. For both microhardness tests, indentation moduli were evaluated from indentation curves using Oliver and Pharr method [8].

Parameters of surface roughness of deposited cermet coatings were measured by confocal laser scanning microscope LEXT 4100 (CLSM). Measurements were done according to ČSN EN ISO 4288 standard [9].

3. RESULTS AND DISCUSSION

The microstructure and morphology of feedstock powder prepared by s&a process together with two different types of carbides are shown in (**Figure 1**). A high percentage of studied particles of feedstock powder were porous, not fully dense and had spherical shape. The presence of Cr_3C_2 phase occurred through individual powder particles. This phase is visible on the surface of feedstock powder particles (**Figure 1d**). On the other hand, WC phase creates the outer shell of feedstock powder where the Ni rich phase is mainly localized. Ni matrix surrounds carbides and binds them together. The Cr_3C_2 phase is usually larger in comparison to WC phase (see **Figures 1 c, d**)

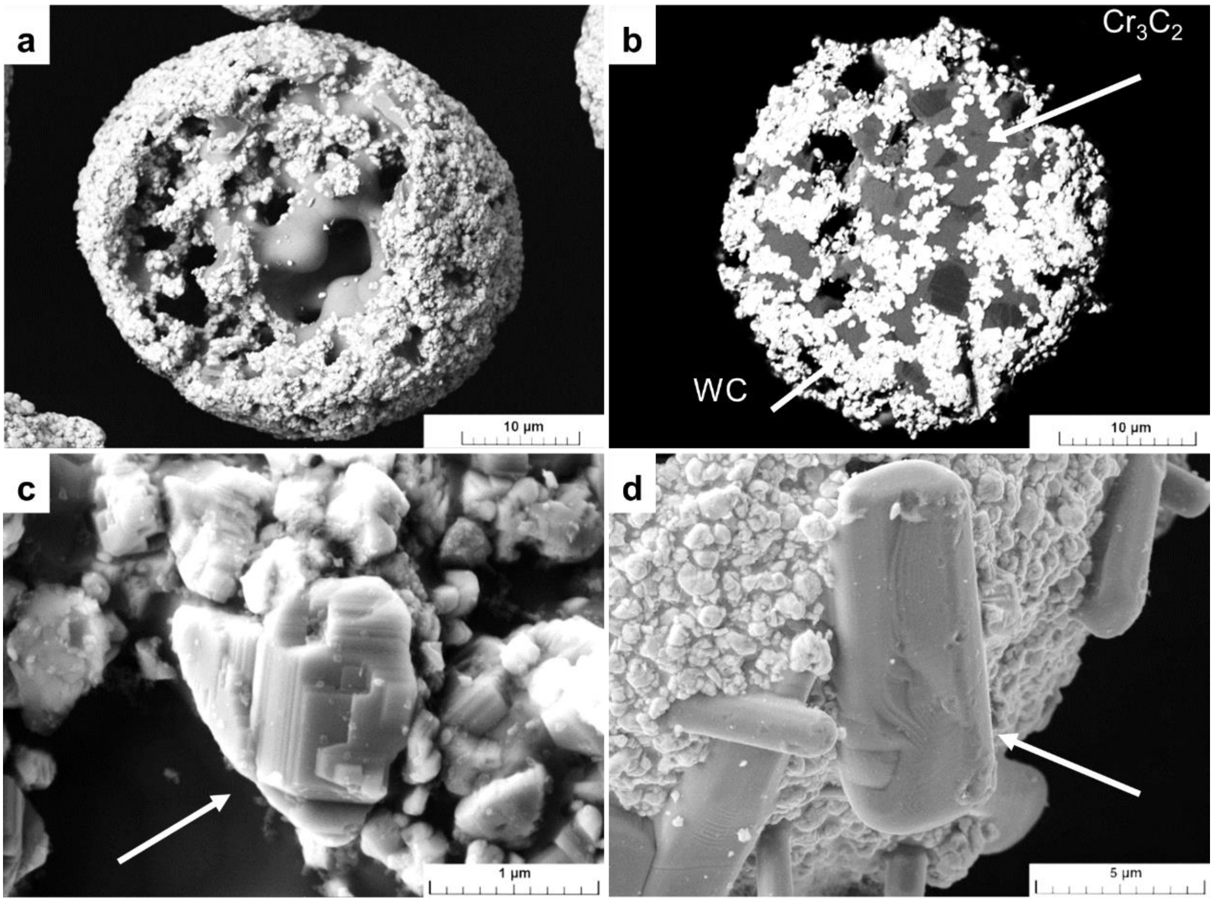

Figure 1 Microstructure and morphology of powders acquired on scanning electron microscope: a) single powder particle, b) cross-section of particle, c) wolfram carbide, d) chromium carbide

Figure 2 shows microstructures of coatings deposited with all three deposition parameters. Differences between samples prepared by different parameters are recognizable. The highest value of total porosity was found in the case of medium parameters because higher particle velocity and the lowest temperature resulted in the creation of air pockets. The occurrence of globular porosity is practically negligible, see **Table 2**. On the other hand, a high degree of pull-outs, cracks, delamination and other defects can be observed in all coating except the coatings prepared by high parameters. The thickness of coatings varies in the range of 70 -122 µm. At the interface of substrate and coating Al_2O_3.particles are visible. It could be possible that these grit-blasting artefacts could adversely affect the properties of coating in working conditions.

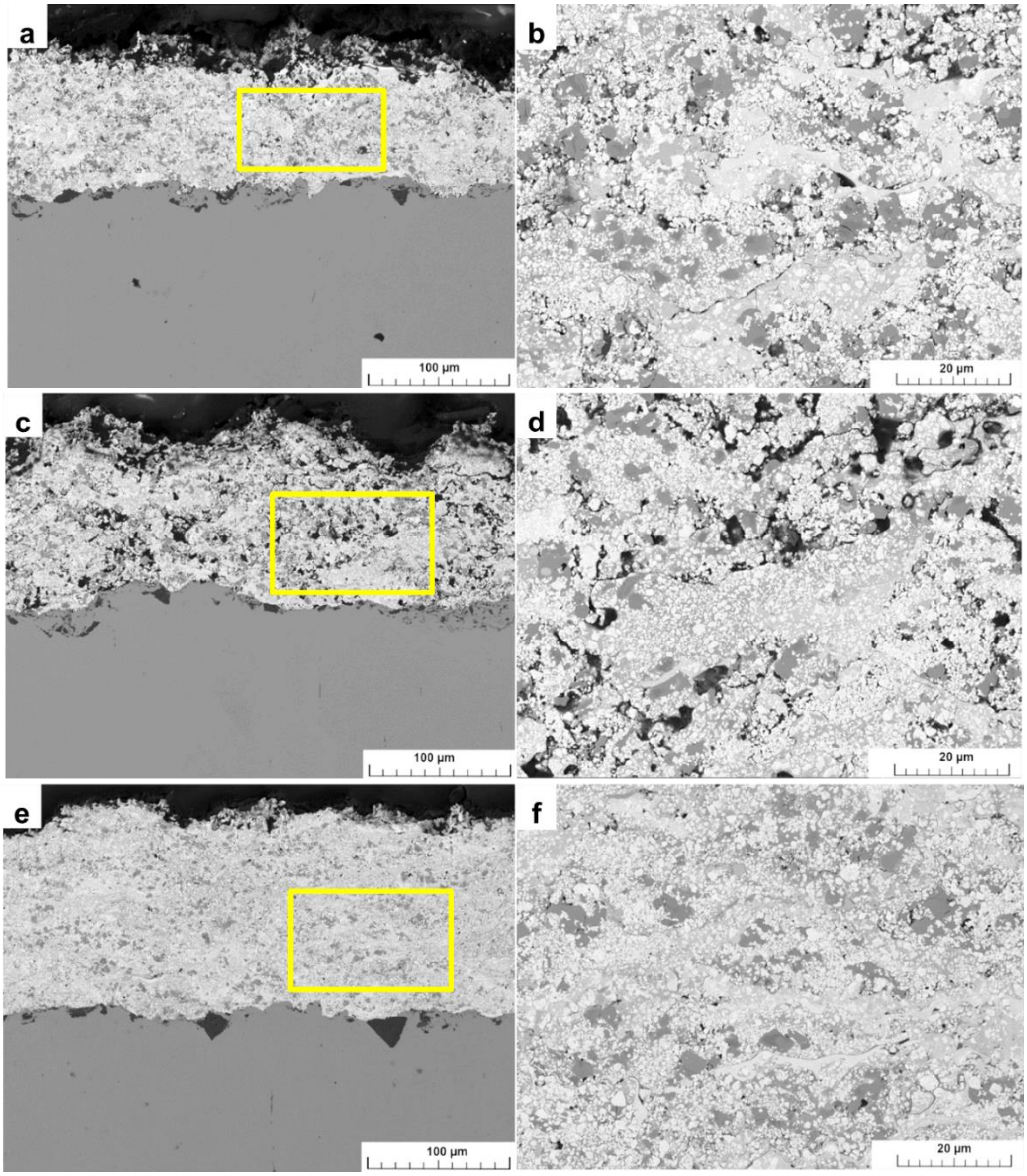

Figure 2 Microstructure of coatings acquired on scanning electron microscope: a, b) LP c, d) MP e, f) HP

Contrast areas in (W, Cr)$_2$C carbides occurred, because of different amounts of Cr and W inhomogeneously distributed in grains, which is caused by metastable or unstable conditions within the spraying process. **Table 2** displays values of total porosity which includes globular pores, cracks and pullouts. The obtained value of total porosity for the coating deposited with HP is lower than the value reported by Fang [10], for the optimal coating process indicating, that there is still room for improvement of the deposition process to obtain coatings with superior properties. Values of hardness and indentation modulus are increasing with the increase of deposition parameters more precisely with higher velocity.

Table 2 Mechanical properties, porosity and roughness of deposited coatings

Spray Parameters	Hardness HV0.1	EIT (GPa)	HIT (GPa)	Globular porosity (%)	Total porosity (%)	Ra (µm)
LP	1176 ± 150	152 ± 26	7.5 ± 1.8	0.26 ± 0.04	2.68 ± 0.73	8.8 ± 0.6
MP	1319 ± 289	188 ± 27	9.8 ± 2.2	0.27 ± 0.03	15.43 ± 1.58	8.7 ± 0.4
HP	1464 ± 264	279 ± 33	12.3 ± 2.9	0.18 ± 0.07	1.01 ± 0.28	7.1 ± 1.0

Hardness HV0.3 in the coating deposited with HP (the lowest total porosity) is 1358 ± 130, HIT value stays the same (12.4 ± 1.5 GPa), however EIT drops to (241 GPa). For the same applied force, Oechsle [6] acquired the hardness value of 1300 HV0.3. Berger in his work [11] stated even lower values 1126 HV0.3. The difference can be caused by the higher involvement of non-stoichiometric carbide (W, Cr)$_2$C and a production of W_2C due to decarburization as observed in XRD spectra (**Figure 3**).

Table 2 also displays roughness parameters. It is important to notice that values of Ra decrease with higher deposition parameters. Nevertheless, these values are still approximately two times higher than reported by Jonda [12]. Higher roughness can negatively affect fatigue life and corrosion resistance of coatings.

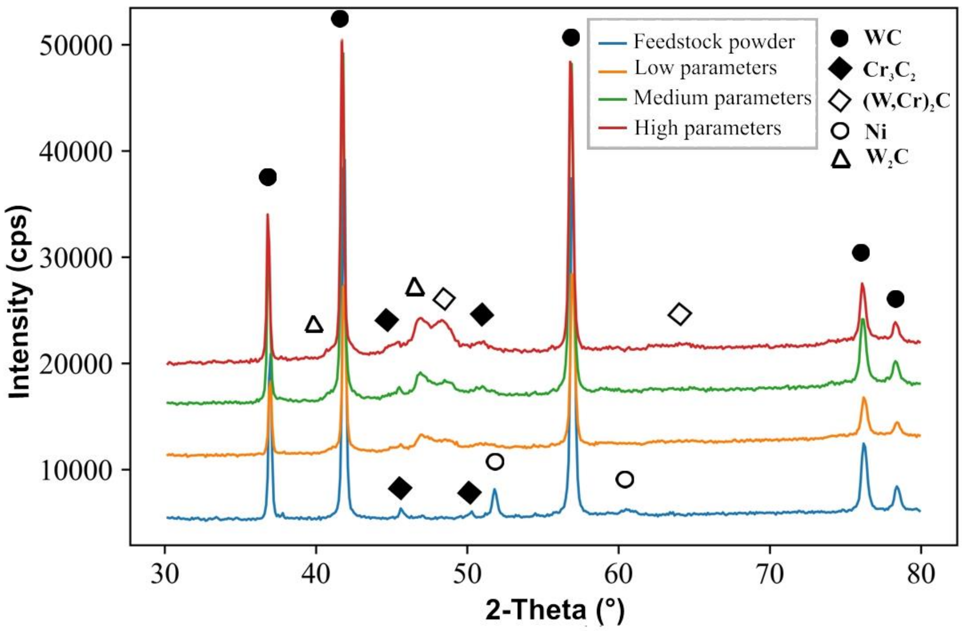

Figure 3 Diffraction patterns of feedstock powder and HVOF sprayed samples of WC-CrC-Ni deposited with different parameters

Figure 3 present the XRD spectra of powder and coatings deposited with three deposition parameters. Different phases are observed in deposited coatings and in the feedstock powder. The process of spraying caused the formation of (W, Cr)$_2$C and W_2C phases. The intensity of the (W, Cr)$_2$C increased with the increase in deposition parameters suggesting a higher volume fraction of this phase. Unlike to the feedstock powder spectrum, coatings spectra show that there is no occurrence of Ni rich phase. This might be caused by severe deformation of Ni rich phase during the HVOF process which could result in a formation of nanocrystalline or amorphous Ni rich phase.

4. CONCLUSION

Based on measured data and microstructural observations of HVOF sprayed WC-CrC-Ni coating, the following conclusions can be drawn. Decreasing the temperature of the particles in-flight only increases the probability of higher total porosity occurrence due to the creation of air pockets in splats within the process. Globular porosity values are negligible in comparison to total porosity values. Mechanical properties are strongly dependent on the oxygen flow and velocity of particles in the spray stream. The highest values of microhardness, indentation modulus and indentation hardness were obtained for the highest deposition parameters. XRD spectra show an increase in the intensity of (W, Cr)$_2$C peak with the increase in deposition parameters suggesting a higher amount of this phase, which can be the origin of the preeminent hardness of this coating.

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