ORIGINAL STUDY

THE EFFECT OF WC-12CO POWDER PARTICLE SIZE ON PROPERTIES OF A HIGH VELOCITY OXYGEN-FUEL SPRAYING COATING

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Abstract. *In the petroleum industry, erosion and corrosion of critical components such as valves and seat rings cause serious operational challenges. To minimize these problems, thermal spray coatings are widely used, especially those created using high velocity oxygen flame (HVOF) technology. These coatings are widely recognized for their high wear resistance and ability to perform effectively under extreme conditions. This study investigates the effect of powder particle size distribution on the structural, mechanical and tribological properties of WC-12Co coatings produced by HVOF. Three powder size fractions are considered in the study: 0-20 µm, 30-40 µm and* 40-50 *µm. Stainless steel substrates were coated and the resulting coatings were analyzed for porosity, hardness, wear resistance and microstructure using scanning electron microscopy (SEM), hardness measurements and tribological tests. The results showed that finer powder fractions resulted in denser coatings with lower porosity and higher hardness values reaching 890 HV for the 40-50 µm fraction. Tribological tests showed that coatings from the 40-50 µm fraction exhibited the highest wear resistance. These results emphasize the importance of selecting optimal powder fractions to improve the performance of WC-12Co coatings, making them ideal for aerospace and petroleum applications where durability and wear resistance are critical.*

Keywords: WC-12Co coatings, High-Velocity Oxygen-Fuel Spraying (HVOF), wear resistance, friction coefficient.

1. Introduction

Erosion and corrosion of valves in the oil industry is a serious problem due to the presence of suspended sand particles in the oil and gas flow. This leads to erosion of critical components such as valves and seat rings, which in turn increases operating costs [1]. Advanced thermal spraying techniques have been developed to address this problem in harsh operating environments such as high-pressure subsea operations [2, 3].

These advanced coating technologies significantly improve component wear resistance, reduce the risk of accidents and extend equipment life. The high adhesion and density of the coating provides excellent protection against erosion and corrosion, which is especially important in extreme operating conditions. Thus, the use of thermal spray technology in the oil industry is an effective solution for extending equipment life and reducing operating costs.

HVOF technology is widely used for surface hardening. Compared with other methods, HVOF is characterized by extremely low heat generation, high flame speed and relatively low temperature, which makes it an important technology for obtaining high performance wear and corrosion resistant coatings. It has found wide application in the surface treatment of pumps, valves, impellers and bearings.

Tungsten carbide (WC) based coatings reinforced with a cobalt matrix (WC-12Co) and obtained by high velocity oxyfuel spraying (HVOF) are a promising material for use under high wear load conditions. Studies show that the HVOF technique can produce coatings with high density and low porosity, which improves the mechanical properties and wear resistance of such materials [4, 5]. The specific combination of tungsten carbide hardness and cobalt plasticity creates coatings that can effectively resist abrasive wear and corrosion

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even in aggressive environments, making them ideal for use in the aerospace and petroleum industries [6-8]. WC tungsten carbide coatings are widely used in various industries to protect key mechanisms [9], including industrial gas turbines, ball valves, and aircraft landing gear shafts [10]. By optimizing the HVOF spraying process, WC coatings can be achieved that exhibit strong bonding, excellent density, high carbide phase content, corrosion resistance, and excellent wear resistance [11-15]. Among the various WC tungsten carbide coatings, WC-Co coatings, in which cobalt (Co) acts as a bonding component, are the most common. The presence of cobalt Co helps to increase the bond strength between the WC solid phase and the substrate, which significantly affects the performance of the coating. In addition, WC-12Co coatings exhibit high compressive strength and modulus of elasticity, which favors their application in components subjected to high mechanical stresses. An important aspect is also the low coefficient of thermal expansion of this material, which prevents the occurrence of thermal stresses and cracks under changing temperature operating conditions [16]. Thus, WC-12Co coatings obtained by the HVOF method offer an excellent combination of mechanical and physicochemical properties, which confirms their high technological and commercial value.

The purpose of this study is to investigate the effect of the fractions of initial powders on the microstructure, phase composition, hardness and wear resistance of WC-12Co metal-ceramic coatings.

2. Materials and methods

Stainless steel 12X18H10T was used as a substrate material, which was pre-polished and sandblasted with electrocorundum under pressure of 0.6 MPa to increase the adhesion of the coating with the substrate. the chemical composition of the substrate is given in Table 1.

WC-12Co powder produced by XTC company (China), ISO 9001 certification, was used for spraying. The powder was sieved on a Retsch AS 300 sieving machine using sieves with sizes 0-20, 30-40 and 40-50.

Table 1. Chemical composition of 12Cr18Ni10T stainless steel (wt %).

Fe	Cr	Ni	Mn	Ti	Si	Cu	C	P	S
67	17-19	9-11	2	0.4-1	0.8	0.3	0.12	0.035	0.02

WC-12Co coating was deposited on the substrate using a LH-5000 (China) HVOF, the specific parameters and codes of the experiments used in the spraying process are summarized in Table 2.

Table 2. Spraying modes of WC-Co coatings.

Code	A1	A2	A3
Fraction size	0-20	30-40	40-50
Parameter modes on the gas control panel		Optimal values	
Propane pressure		2.9 bar	
Oxygen pressure		5 bar	
Compressed air pressure		3.2 bar	

The HVOF principle is that large volume combustion gases are fed into the combustion chamber. Combustion takes place inside at very high pressure. They are then fed into a long confining nozzle or cylinder through which they exit the device, creating a supersonic gas jet with very high particle velocities. The powder particles are introduced into the stream, heated and directed towards the substrate on which the coating is formed (see Fig. 1). At such a high velocity, the particles have a shorter residence time in the high-temperature gas environment, which makes it possible to obtain coatings with very low porosity, low oxidation coefficient, and high adhesion to the substrate.

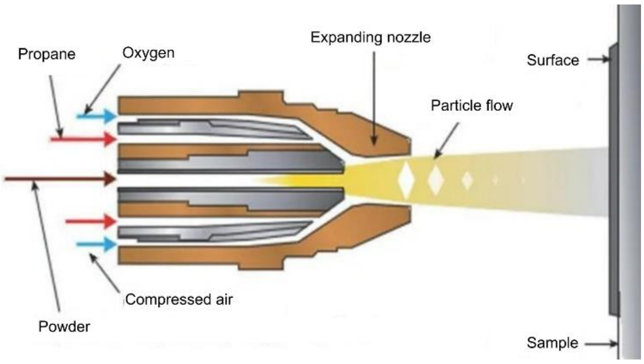

Fig. 1. Schematic representation of the HVOF method.

Structural studies, porosity and microhardness measurements of the coatings were performed on cross-sectional micro-sections. The cross-sectional of the coatings was characterized using TESCAN Vega 4 LMH scanning electron microscopy (TESCAN, Brno, Czech Republic). Measurement of microhardness of samples was carried out on the cross-section of coatings (10 measurements for each type of coatings) on a microhardness tester GOST R ISO 6507-1-2007 Metolab 502 (Metolab, Russia) at load on the indenter m=500 g and dwell time 10s. Tribological tests for friction and wear were performed on a TRB³ tribometer (Anton-Paar, Buchs, Switzerland) according to the standard "ball-disk" method, where a ball with a diameter of 6.0 mm made of 100Cr6 coated steel was used as a counterbody, with a load of 10 N, linear velocity of 3 cm/min and a path length of 100 m.

3. Results and discussion

3.1 Morphology

The microstructure of WC-12Co powder material deposited by gas-thermal spraying is shown in Fig. 2 Two detectors were used: SE (secondary electrons) and BSE (backscattered electrons). The image obtained with the backscattered electron (BSE) detector shows the distribution of WC and Co: lighter areas correspond to tungsten (WC) and darker areas to cobalt (Co).

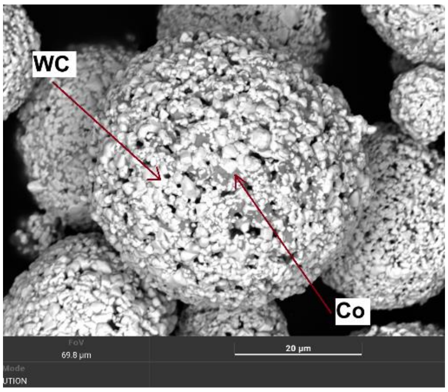

Fig. 2. SEM pictures morphology of WC-12Co powder.

Fig. 3 shows images of the initial WC-12Co powders. The sphericity of the powder indicates its good flowability. Different powder particle size distributions can significantly affect the different physical properties of thermal spray coatings, they can cause non-uniform material distribution which leads to void formation and inhomogeneous geometry of sprayed coatings [17, 18]. Therefore, it is important to select powder raw materials with appropriate particle size distribution when using different thermal spraying processes and process parameters.

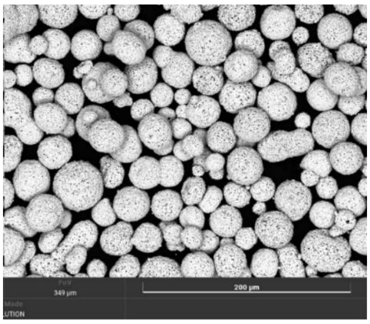

Fig. 3. SEM pictures of-12Co powders before sieving.

In order to ensure reliable and stable comparability of the characteristics of coatings in this study used powder size 5-50 micrometers, which was sieved into three fractions: 0-20 µm, 30-40 µm and 40-50 µm (Fig. 3, 4, 5) all images are made at a field of view equal to 349 µm. This allowed us to conduct comparative studies and evaluate the influence of fractional composition on the properties of coatings obtained by HVOF method.

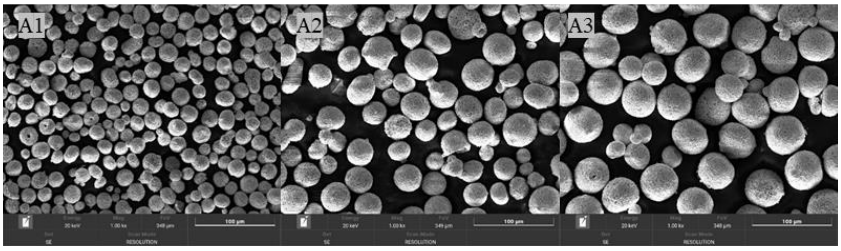

Fig. 4. SEM pictures of powder after sieving.

Fig. 5, 6 and 7 show the surface morphology of the WC-12Co coatings obtained by the HVOF method. The coatings show the presence of both fully melted and partially melted regions, with a small number of fragmented particles.

WC-based ceramic spraying powders have high melting temperatures of about 3000°C. In the HVOF spraying process, most of the metal powder is heated to a temperature close to the melting point [19]. The molten droplets impact the substrate surface at extremely high speed, solidify and are deposited layer by layer to form a dense and cohesive coating.

Fig. 6, 7, 8 also show that the number of unmelted particles decreases significantly with decreasing powder fraction. This contributes to the formation of denser and more homogeneous coatings.

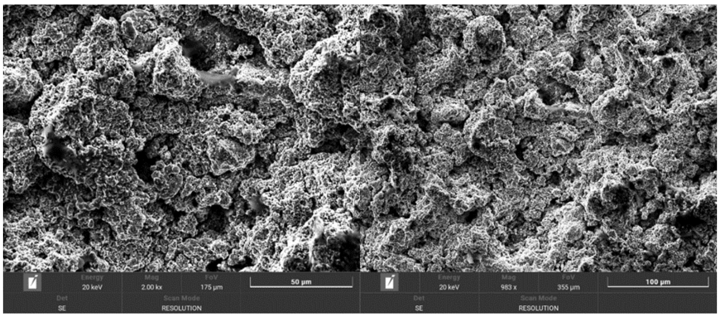

Fig. 5. SEM pictures of WC-12Co coating fraction 0-20 µm.

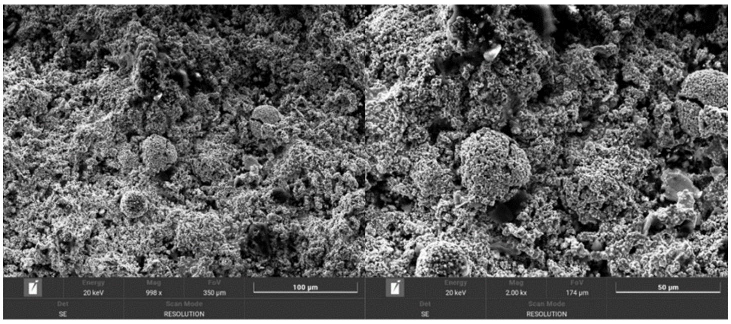

Fig. 6. SEM pictures of WC WC-12Co coating 30-40 μm fraction.

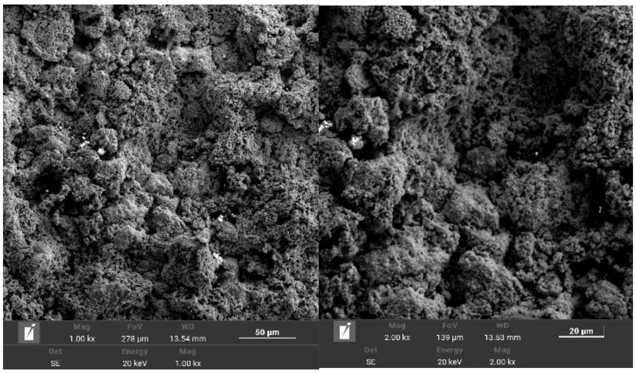

Fig. 7. SEM pictures of WC WC-Co coating 40-50 μm fraction.

The thickness of WC-12Co coatings varies from 700 to 850 μm. The coatings have a rather highly compact structure, which is characteristic of this powder. The indenter prints in hardness measurements show cracks, indicating that the coatings are highly porous.

Comparative analysis showed that the coatings obtained from powder fractions of 40-50 μm and 30-40 μm were more porous than coatings from powder fractions of 0-20 μm. This is probably due to the smaller particle size in the latter case, which contributes to better density and lower porosity of the coating.

3.2 Microhardness

Fig. 8 shows the results of studies of microhardness distribution of coatings obtained by HVOF method with different powder fraction. The studies showed the following results: The microhardness of stainless steel is 2-3 times less than that of coatings applied by HVOF method. The microhardness near the interface between the coating and substrate increased slightly to about 350 HV. This indicates that the exposure during powder particle deposition had some hardening effect on the substrate. The microhardness of the coatings deposited by the HVOF method ranged from 350 to 890 HV. Fig. 9 shows the SEM morphology of the cross section of coatings of different fractions with indenter imprints. As can be seen from the images, coatings with large pores did not crack under loading, however, coatings with small pores developed cracks at the loading points. Fig. 10 also shows the microhardness distribution graph.

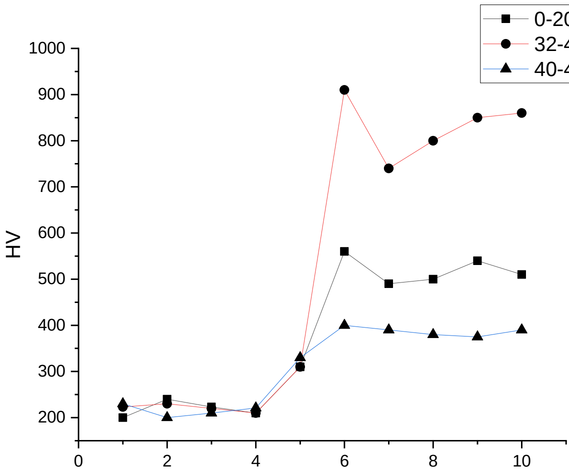

Fig. 8. Microhardness of samples.

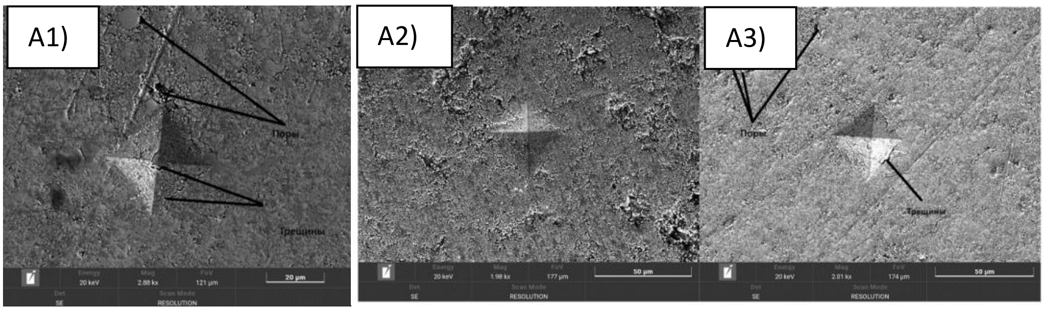

Fig. 9. Images of prints of the coating microhardness study (A1) 0-20 (A3) 40-50 (A2) 30-40.

You can see from the charts that:

- for the powder fraction 0-20 µm, the microhardness varied between 400-500 HV.

- for the powder fraction of 30-40 µm the microhardness was 290-340 HV.

- The optimum coating hardness was achieved at a powder fraction of 40-50 µm, where the microhardness varied between 700-890 HV.

These results emphasize the importance of powder fraction selection to achieve the desired coating performance.

3.3 Tribology

In the section concerning the tribological studies (Fig. 11), it was found that by varying the fractions of the initial powder, the average coefficient of friction of the coatings had the following values:

- µ = 0.552 for 0-20 µm fraction
- µ = 0.516 for 30-40 µm fraction
- µ = 0.510 for 40-50 µm fraction

Thus, the coefficient of friction does not change significantly with changing the powder fraction. However, it was observed that the maximum wear resistance was characteristic of the coating deposited with powder with 30-40 µm fraction (v = 2.789E-005). This is attributed to the increase in the content of WC carbide phase in the coatings [14]. Nevertheless, the difference in wear volume between coatings with fractions of 0-20 µm and 30-40 µm was not noticeable.

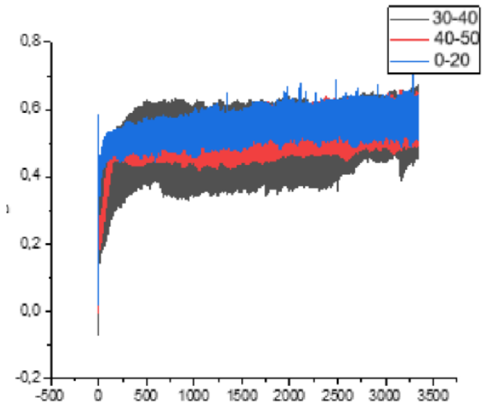

Fig. 10. The microhardness distribution graph.

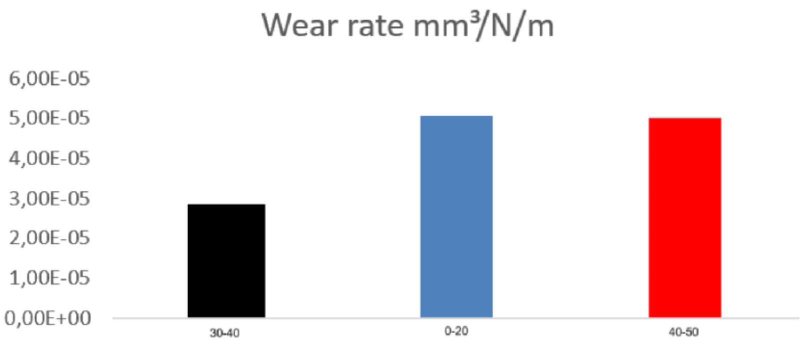

Fig. 11. Graph of friction coefficient versus friction path (a) and wear volume versus initial powder fractions (b).

4 Conclusion

In conclusion, the study demonstrates the significant impact of powder particle size on the microstructure, mechanical properties, and wear resistance of WC-12Co coatings produced by high-velocity oxygen-fuel (HVOF) spraying. Coatings produced from finer powder fractions (0-20 μm) exhibited superior characteristics, including lower porosity, higher density, and enhanced hardness, with values reaching up to 890 HV for the 40-50 μm fraction. The tribological tests revealed that the 40-50 μm fraction had the highest wear resistance, emphasizing the role of powder size in achieving optimal coating performance. These findings highlight the critical importance of selecting the appropriate powder fraction to improve the coating's performance, making WC-12Co coatings ideal for applications requiring high durability, such as in the aerospace and petroleum industries. The study underscores the effectiveness of HVOF spraying in producing coatings with high wear resistance and mechanical strength, contributing to the extension of the service life of components in harsh operating environments.

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Conflict of interest

The authors declare no conflict of interest.

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