THE SPRAYING PARAMETERS OPTIMIZATION OF THE HVOF STELLITE 6 COATING

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Abstract

The CoCrWC alloy, well known as Stellite Alloy 6, is the most widely used alloy in the Co-based group of alloys. It has an excellent resistance to many forms of wear and corrosion over a wide range in temperature. Their exceptional wear resistance is due mainly to the unique inherent characteristics of the hard carbide phase dispersed in a CoCr alloy matrix. Stellite Alloy 6 has an outstanding resistance to seizing or galling as well as cavitation erosion and retains a reasonable level of hardness up to 500°C. It is available in many product forms – castings, wrought bars, sheets etc. It is ideally suited to a variety of hardfacing processes and can be turned with carbide tooling. Examples include valve seats and gates; pump shafts and bearings, erosion shields and rolling couples. The thermal spraying is one of the technologies that can be used for Stellite Alloy 6 deposition on the parts surface. To preserve its superior properties, it is necessary to find the optimal spraying parameters. During spraying, the undesirable structure features, such as pores, oxides or unstable phases, can occur. The process of spraying parameters optimization aims to find the parameters that keep the occurrence of the above mentioned features to a minimum amount. In the paper, the methodology of parameters optimization process is described together with the results of coating properties evaluation. Based on the results, the best spraying parameters were found to be used for further spraying of commercial applications.

Keywords: HVOF, spraying parameters, optimization, Stellite 6

1. INTRODUCTION

The CoCrWC alloy, commonly known as Stellite 6 is in the form of bulk material characterized [1] by a chemical composition containing (27-32)%Cr, (4-6)%W, (0,9-1,4)%C and the Co-base. The hardness of bulk Stellite 6 ranges from 36 to 54 HRC or from 380 to 490 HV. Its microstructure composes from Co fcc dendrites surrounded by Co phases and carbides. Cr content ensures resistance to oxidation and corrosion and strength thanks to the formation of M7C3 and M23C6 carbides. The content of Mo and W also contributes to the strength of the alloy by formation of MC and M6C carbides and Co3(Mo,W) intermetallic phases. The possible Ni, C and Fe additives increase the stability fcc structure in Co matrix and enables the alloy to be stabile up to the melting temperature (1495°C), while the Cr, Mo and W tend to be stabile at low temperatures (up to 417°C) in hcp structure.

The hypo-eutectic structure composes from hard wear resistant carbides embedded in the tough matrix. It offers the combination of the resistivity to abrasive and sliding wear and the resistivity to cavitation wear, galling and seizing. When self-mated, it has very low coefficient of friction of 0.12. Its resistivity to cavitation-erosion wear is ten times higher than that of 304 stainless steel. It has high resistance to a variety of corrosive media and excellent oxidizing resistance to about 1095°C. It resist to an influence of oxidation acids such as acetic, formic, phosphoric and low concentration sulphuric. It is not recommended to use for reducing acids such as hydrochloric.

The superior Stellite 6 properties are widely used in surface engineering for coating of the surfaces of highly stressed components in many branches of industry. The most spread technology for Stellite 6 deposition is welding, the classical [2], and the laser cladding [3,4]. It offers the well adhered coatings with minor porosity, but suffers from the high thermal and residual stress. Another possibility to deposit the Co-based alloys is the technology of thermal spraying. Compare to the welded overlays, the thermally sprayed coatings are more beneficial from the stress point of view, but on the other hand are less adhered to the parts surface and can include some amount of pores and oxides.

To minimize the occurrence of unwonted structure defects, the proper spraying parameters have to be found. The spraying parameters vary in dependence on used spraying device and used powder material. Not only material composition, but also the way of powder manufacturing and the size mesh matters.

The mechanical and corrosion resistance properties of HVOF sprayed Stellite 6 coating in comparison with Ni-based coating were evaluated in [5,6]. In this study, the hardness of Stellite 6 coating reached 800-900 HV. It was shown, that the corrosion resistance of the coating is ensured by the formation of Si and Cr based oxides and CoC rand NiCr based spinel oxides on the coating surface and on the boundaries of individual splats. The oxidation process is fast from the beginning, later the increasing amount of oxides protect the coating from further oxidation. Similar mechanism of corrosion resistance was described also for plasma-sprayed Stellite 6 coating [7]. The wear resistance of Stellite 6 coating was compared with several other materials in [8]. Based on the results, the Stellite 6 was recommended for application on the surface of turbine blades and pumps.

2. EXPERIMENTAL AND RESULTS

2.1 Spraying parameters

To design the set of the spaying parameters, the parameters recommended by the powder producer was used as a reference. The amount of oxygen and fuel was varied to obtain 9 sets of parameters. The flame temperature (represented by equivalent ratio Φ) and velocity (represented by combustion pressure p) was varied independently.

Used powder material: Stellite 6, FST 484.33

Tab. 1. Variable spraying parameters – designation of the samples

p [psi] \ **Φ**	**0,85**	**0,98**	**1,1**
100	**1**	**2**	**3**
109	**4**	**5**	**6**
119	**7**	**8**	**9**

Constant spraying parameters:

Spraying distance: 360 mm; Carried gas: nitrogen; Carried gas flow: 6,5 l/min; Traverse speed: 250 mm/s; Offset: 6 mm

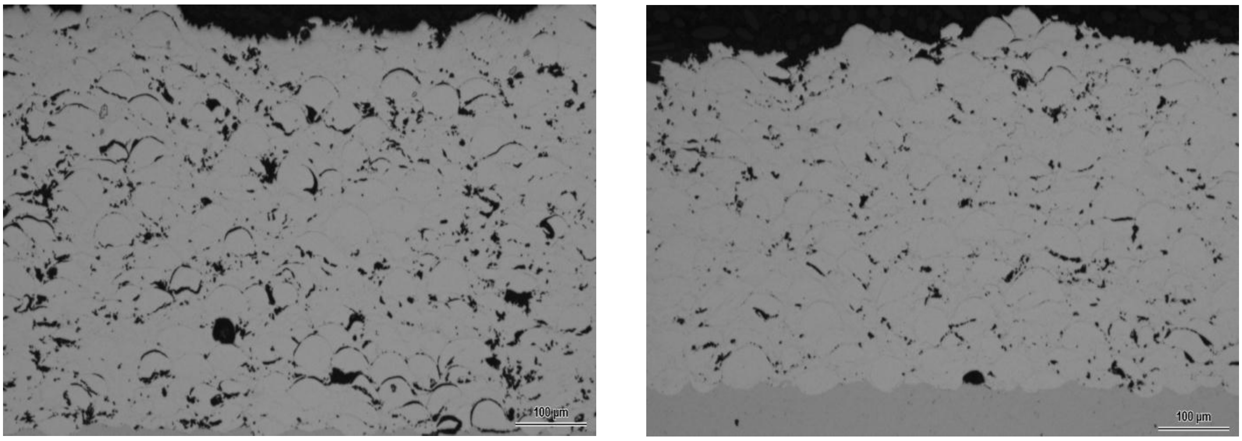
2.2 Testing equipment

The coated samples were grinded and polished using automatic Struers grinding and polishing equipment. The microstructure of the coatings were evaluated by optical microscope Nicon Epiphot 200 using magnification 50x and 100x, SEM Quanta 200 from FEI using magnification 200x, 1000x and 3000x and HIROX KH 7700 using magnification 700x. The thickness of the coatings was measured on the coatings cross-sections by optical microscope. For each coating, at least 5 measurements were done and the average value was calculated. The surface roughness was measured by surftester Mitutoyo SJ-201P, according to DIN EN ISO 4287. The reported values are average from at least five measurements. The surface hardness HR15N was measured on the as-sprayed coatings surfaces using hardness tester

Rockwell HT 8003. The reported values are average from at least 5 measurements. The coating microhardness HV0.3 was measured on the coatings cross-sections. The reported values are average from at least seven measurements. The abrasive wear resistance of the coatings was evaluated by Dry Sand/Rubber Wheel test according to ASTM G 65. The reported values are the average from two measurements.

2.3 Coatings microstructure

In the Figure 1a, the poorest microstructure of the coating, sprayed by parameters 4, is shown. The high amount of porosity, combined with low interspalt cohesion, can be caused both by low flame temperature and low particle velocity. On the other hand, the microstructure of the coatings, sprayed by parameters 7, is much better; even if the equivalent ratio, representing the flame temperature, is comparable to parameters 4 (see Fig.1b.)



a) b)

Fig. 1 Coatings with the worst (a) and the best (b) microstructure

2.4 Coatings surface roughness

In the Fig. 2, the dependence of Ra and Rz parameters on the spraying parameters can be seen. For characterization of not-periodical surface, the Rz (average distance between the highest peak and lowest valley in each sampling length maximal profile height) value of coating is a better parameter than usual Ra.

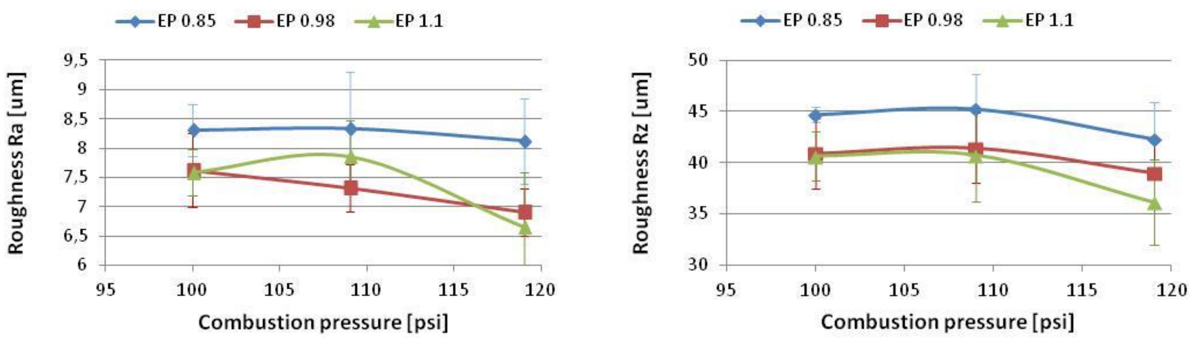


Fig. 2 Coatings surface roughness parameters in dependence on spraying parameters

From both graphs, it is obvious, that the coatings surface roughness is influenced by both temperature as well as velocity of the sprayed particles. The coatings become smoother with increasing temperature and increasing velocity, when the better flattering of the particle after impact is enabled.

2.5 Relative deposition efficiency

The relative deposition efficiency is determined as the thickness per pass. The thickness of the coatings was measured on the coatings cross section and then it was divided by number of spraying passes. It enables to compare the efficiency of spraying process between samples sprayed by different parameters without knowledge of amount sprayed powder and volume of coating materials. As it can be seen from the Figure 3, the relative deposition efficiency is lower for lower temperature and for higher velocities. The temperature corresponding with Equivalent ratio 0.85 is from the efficiency point of view, suitable for deposition. The EP0.98 and EP 1.1 gives similar results. The higher impact energy has a positive effect on the deposition efficiency.

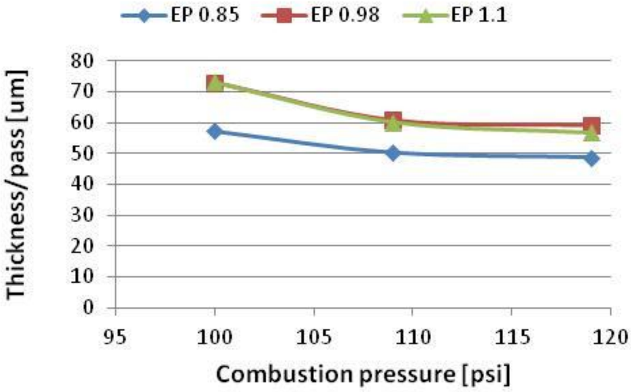


Fig. 3 Relative deposition efficiency in dependence on spraying parameters

2.6 Surface hardness and microhardness

With respect to scatter of hardness value, the overall trend of the hardness and microhardness can be described as increasing with combustion pressure. While the microhardness seems to increase together with increasing of equivalent ratio, the surface roughness decreased. The influence of combustion pressure can be explained by peening effect of impacting particles, introducing the inner compressive stress into the coating. The influence of temperature is not significant in this case.

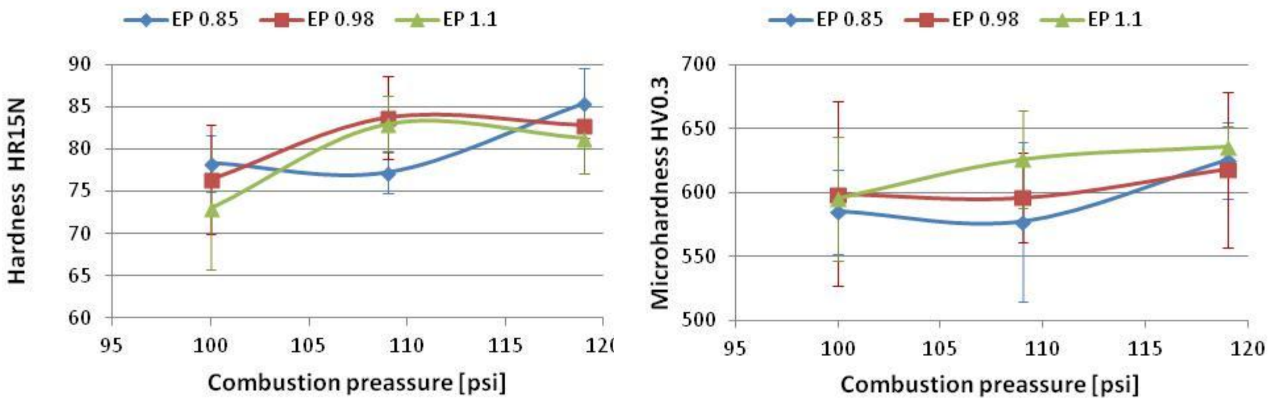
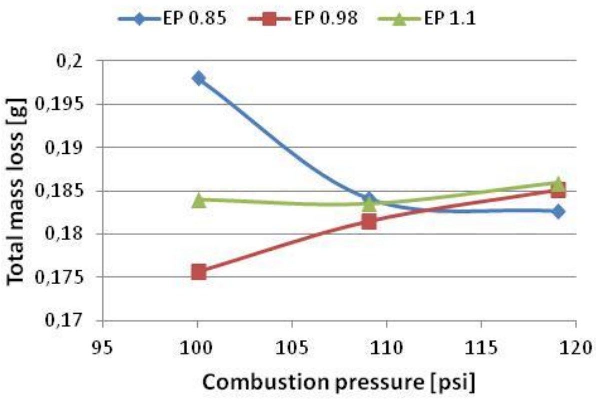


Fig. 4 Surface roughness and microhardness in dependence on spraying parameters

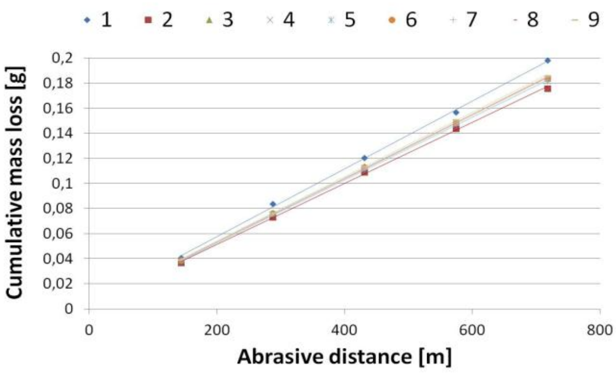
2.7 Abrasive wear resistance

The abrasive wear resistance of the materials depends both on the hardness and fracture toughness. In the case of thermally sprayed coatings, the toughness is connected with the intersplat cohesion of the coating.

The results of the Dry Sand/Rubber Wheel test, expressed by total mass loss [g], are shown in the Figure 5a. With the exception of the lowest particle velocity, it corresponds with the results of surface hardness (see Fig. 4). In the Figure 5b, the cumulative mass loss [g] in dependence on the abrasive distance show, that the difference between individual coatings are very low, almost negligible. The influence of the spraying parameters is under the resolution of ASTM G 65 method.



a)



b)

Fig. 5 Total (a) and cumulative (b) mass loss in dependence on spraying parameters

The wear mechanism of the Stellite coating was evaluated by SEM (Fig. 6). The ploughing was found to be the main wear mechanism. In some places, the rests of the Al_2O_3 sand is embedded to the worn surface. The profile of worn surface is shown in the Figure 7. The worn surface is very smooth, the depth of the wear scars does not exceed 1,5 μm.

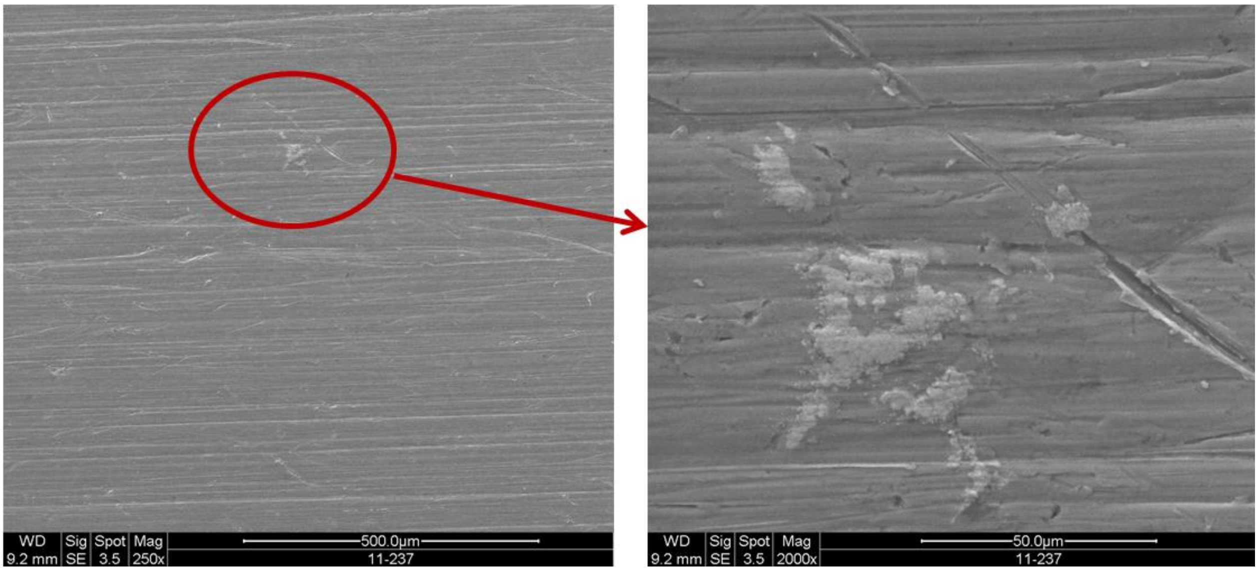


Fig. 6 Wear mechanism evaluated by SEM – coating no. 8

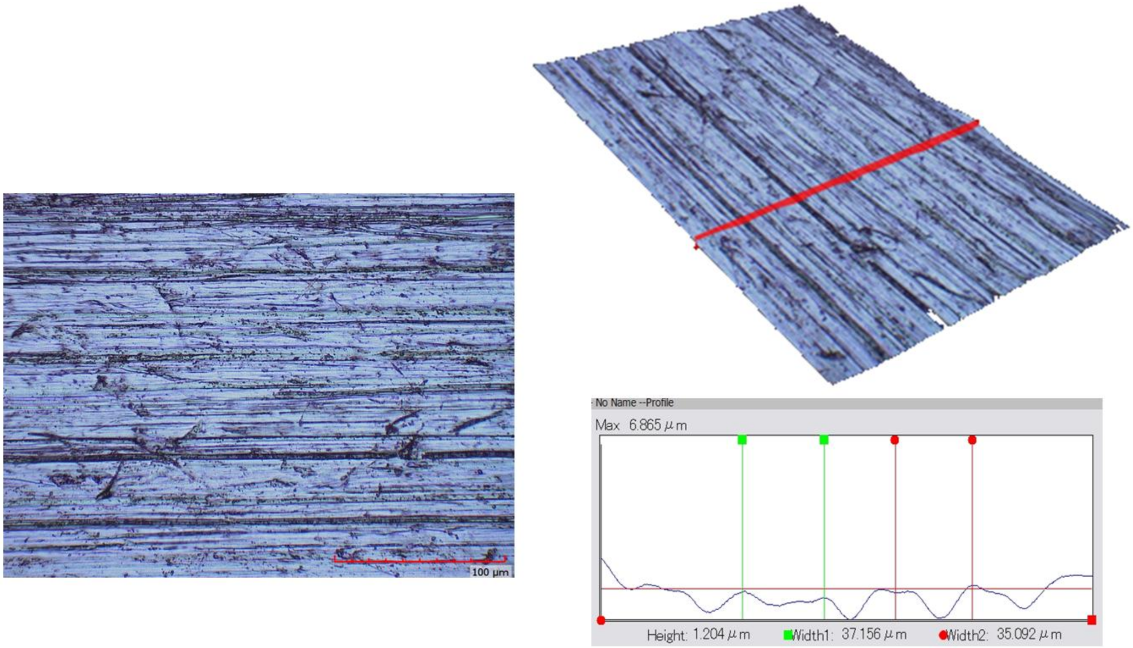


Fig. 7 Wear mechanism evaluated by HIROX – the wear track profile – coating no. 8

CONCLUSION

Based on the realized evaluation of influence of spraying parameters on the properties of HVOF sprayed Stellite 6, the recommendation of the best spraying parameters can be done. The best results of mechanical properties were achieved using parameters 7, 8 and 9. All of them use the highest velocity of particles, impacting the surface. On the other hand, the deposition efficiency of those coatings is the lower compare to coatings sprayed by lower combustion pressure. From this point of view, the parameters 8 is a reasonable compromise and will be further use for commercial purposes.

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