

Stellite-6 surface layers reinforced with hard and refractory WC particles produced on steel for metal forming

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Abstract. This paper presents the selected properties of coatings produced on steel using for metal forming processes such as forging, extrusion or pressing. For the preparation of surface layers the laser cladding with powder technology was applied. The power of laser beam was equal to 550 W and feed rate was 400 mm/min. The aim of presented study was to obtain the microstructure similar to sintered carbide. Microstructure, microhardness, chemical and phase composition as well as corrosion resistance tests were carried out and analysed. It was found that the presence of WC particles in Stellite-6 matrix had a positive influence on mechanical properties, but negative impact on corrosion resistance of produced surface layers in comparison with the unreinforced coating. Using XRD phase analysis, the presence of the hard interstitial phases (WC, W₂C, M₇C₃ and M₂₃C₆) in the matrix were confirmed.

1. Introduction

Modern methods and techniques of surface engineering enable the production of different types of composite and complex coatings. The most frequently reported in the literature are: thermal spraying, plasma and laser remelting of galvanic coatings, diffusion layers or precoat in the form of pastes [1-4]. Laser cladding method [5-12] is at utmost importance for various industrial branches wherein a suitably designed nozzle simultaneously emits the laser beam and adds powder mixtures to it. It is thus possible to easily produce a coating with new unique properties. In contrast to thermal spray, the laser cladding method ensures metallurgical connection with substrate and its minimal remelting. This method allows for extremely precise control of layer thickness. Furthermore generation of small heat affected zone can be considered as the undoubted advantage. Laser cladding is being increasingly used as an alternative to PTA method, furthermore significantly exceeds the capabilities of conventional methods such as TIG. In laser cladding method, additional peripherals such as a powder feeder, the cooling system and laser head are used. Modern control systems are based on CNC programming, making the process can be fully controlled by the operator. Flux of powder is fed into a focused laser beam. Powder materials are supplied from powder feeder through a system of ducts and blown to the center point of laser beam by means of an inert gas or by gravity [13]. The main parameters of laser cladding are: laser beam power, laser beam diameter, powder feed rate and scanning speed. These parameters have a decisive influence on melting rate of substrate. This is important for creating composite coatings described in this work due to the differences in melting point of individual components of powder mixture. There are many publications where the authors describe metal matrix composite coatings (MMC). Due to the presence of hard particles of carbides such as WC, VC, etc. located in metallic matrix, MMC coatings have a much better wear resistance. Microstructure of this



type of coatings is similar to microstructure of sintered materials. So far, majority of studies were focused on production of MMC coatings on Fe-based alloys or Ni-based alloys. However, fewer papers present production of MMC coatings with Co-based alloys, and particularly with Stellite-6 alloy [14-16], although Stellite-6 coatings without hard particles were extensively described [17-19]. This alloy is often used for production of coatings on machine components which operate in conditions requiring high strength as well as good wear and corrosion resistance. Increased temperature does not change these properties.

This paper describes selected properties of Stellite-6 coatings reinforced by 40% of spherical WC particles. Microstructure, microhardness, phase composition and corrosion resistance in a 5% NaCl solution were investigated. The powder mixture containing 60% Stellite-6 and 40% tungsten carbide particles was applied.

2. Research Methodology

2.1. Materials

Low-carbon steel specimens of rectangular shape with dimensions of 20 x 20 x 5 mm were investigated. In this study, powder mixture consisting of Stellite-6 and WC was used. Powder mixture particles were size in the range of 25 – 125 μm and were spherical shape (Figure 1). Before laser cladding process specimens were polished, cleaned with alcohol and degreased by acetone. Chemical composition of steel substrate and Stellite-6 powder used to produced coatings were shown in Table 1. Powders for preparation metal matrix composite coatings were mixing for 2 hours using ceramic ball mill. Powder mixtures were dried for 3 hours at 120°C.

2.2. Laser cladding process

Laser cladding process was carried out using a TRUMPF Laser Cell 3008 5-axis CNC device with TruDisk 1000 laser characterized by mode TEM₀₀ of circular shape. Stellite-6/WC powder mixture was blown into the melt pool using carrier gas (helium). Additionally, both powder and newly created coatings were protect from oxidation using shielding gas (argon). Flow rates of helium and argon were equal to 8 l/min. Scheme of laser cladding process was presented in Figure 2. In this experiment theoretical laser beam diameter was equal to 1.64 mm. Parameters used in the experiment were: theoretical laser beam diameter (d) of 2 mm with 45% overlapping, the power of laser beam was equal to 550 W and its scanning speed was equal to 400 mm/min.

2.3. Microstructure and microhardness test

After laser cladding processes, specimens were cut perpendicular to surface and were polished. A two-step etching procedure was used. First using 2% Nital and second using 3:1 solution of HCl and HNO₃. Specimens microstructures were observed using a Huvitz HRM 300 light microscope. Microhardness of produced MMC coatings was measured by Zeiss microhardness tester using indentation load equal to 100 g and dwell time 15 seconds.

2.4. Phase composition and corrosion resistance study

Phase identification was carried out using PANalytical EMPYREAN X-ray diffractometer using Cu K α radiation at 25 °C. Potentiodynamic corrosion tests in 5% NaCl solution were carried out using a Atlas Sollich – ATLAS 0531 EU&IA potentiostat. The specimens with the area of 50 mm² were studied at constant temperature of 23°C and the rate of potential change was equal to 1 mV/s. The specimens were polarized in the direction of the anode in the potentials range from -1.25 to 0.25 V.

Table 1. Chemical composition of substrate material and Stellite-6 powder [Wt. %].

Material	C	Si	Mn	Cr	Ni	Cu	Ti	W	Fe	Co
S355	0.185	0.128	1.180	0.282	0.135	0.335	0.015	-	Balance	-
Stellite-6	1.2	1.1	1.0	28.0	<3.0	-	-	4.5	<3.0	Balance

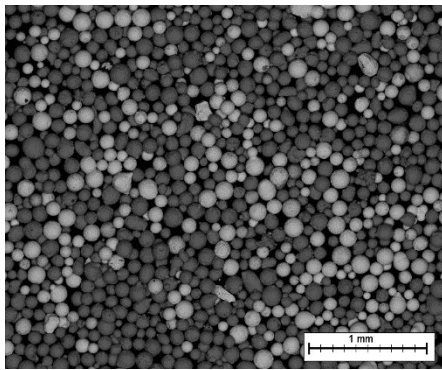


Figure 1. Shape and size of powder mixture particles.

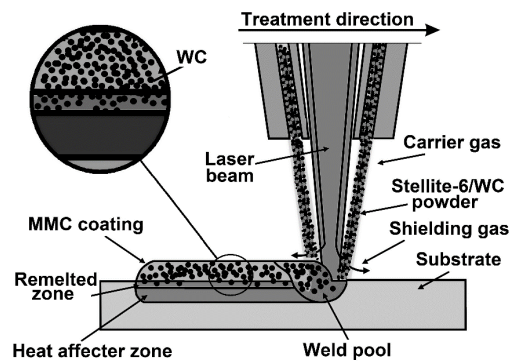


Figure 2. Scheme of laser cladding process.

3. Research results

3.1. Microstructure and microhardness results

The microstructure of the metal matrix composite coating Stellite-6 reinforced with tungsten carbide particles is shown in Figure 3. A very large amount of tungsten carbide particles in the Stellite-6 matrix was found. The carbides have not melted and produced coating had a similar microstructure to the sintered carbides. An uneven distribution of carbide particles was observed. This can be referred to Figure 1, where it can be seen that the two powders did not mix well. This was probably reflected in the microstructure of coating. A characteristic feature of all composite coatings was dendritic microsegregation which were the result of different cooling rate, and thus the different solidification of matrix on a cross section of coatings. The differences in matrix microstructure were the most visible around the tungsten carbides as well as on border between coating and steel substrate.

In Figure 4 the microstructure in Nomarski interference contrast (NIC) is shown. It can be seen that there are distinct differences between the hardness of the matrix and the reinforcing particles. When polishing the samples, the matrix material was more worn compared to the WC particles. The closer the WC particles, the higher hardness the matrix. This is due to the fact that the partial melting of WC particles enriches the matrix and increases its hardness.

Due to the fact that the differences between the matrix and the WC particles are very large, hardness measurements were made only within the matrix. Figure 5 shows the results of microhardness measurements. A hardness of about 700 HV 0.1 was found. The coating material was characterized by similar hardness over the entire thickness. It should be mentioned that the resultant general hardness is much higher, because the WC particles have a hardness of 2500 HV.

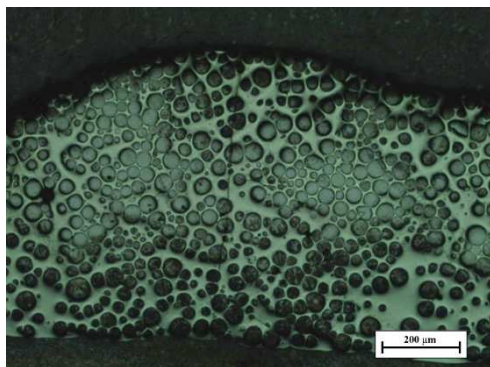


Figure 3. Stellite-6/WC MMC coating produced using laser beam power 550W and scanning speed 400 mm/min.

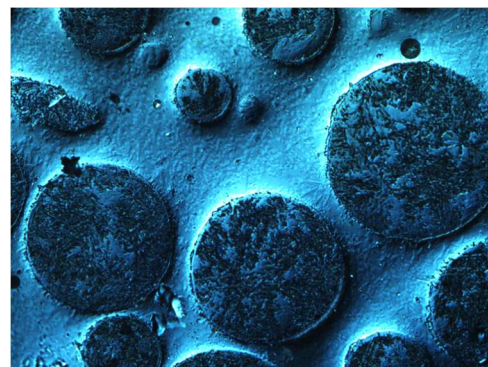


Figure 4. The differences in matrix microstructure around the tungsten carbides.

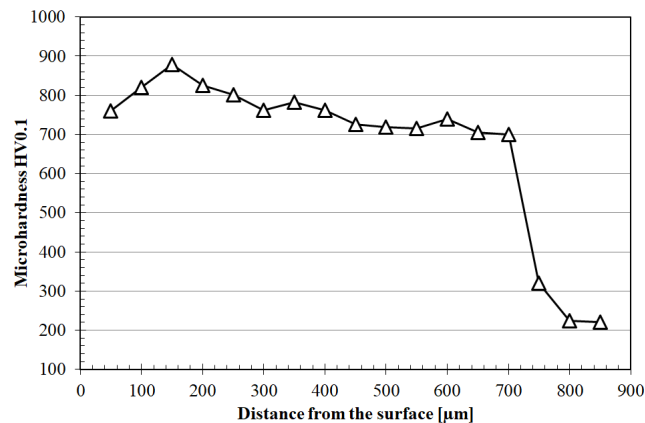


Figure 5. Microhardness of Stellite-6/WC coating.

3.2. Phase composition and corrosion resistance study

Results from XRD pattern of produced Stellite-6/WC specimen was shown in Figures 6. XRD studies were carried out for the coatings produced using 550 W and scanning speed 400 mm/min. In produced coatings WC, $M_{23}C_6$ and M_7C_3 phases were found. M_7C_3 phase was very intense and evident, while $M_{23}C_6$ phases were slightly visible and very difficult to identify. The presence of these phases influence significantly increased microhardness coatings.

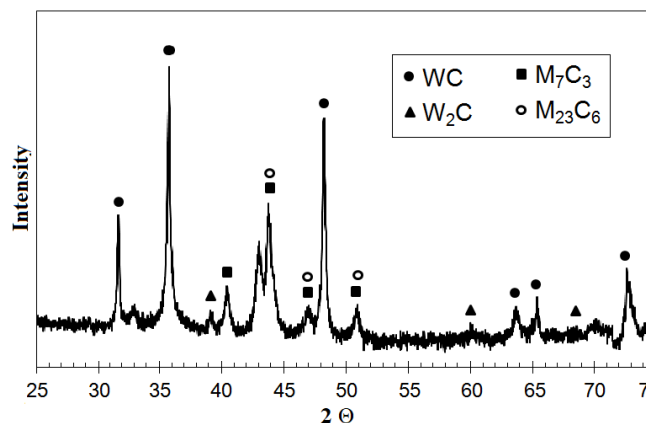


Figure 6. Phase composition of Stellite-6/WC coating.

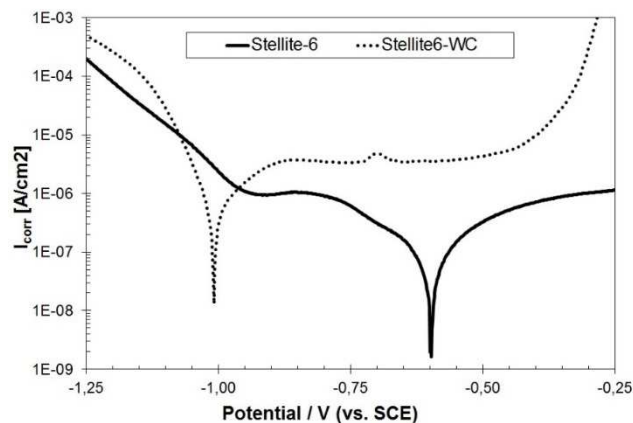


Figure 7. Comparison of corrosion resistance of coatings containing WC particles and without reinforcing particles.

In Figure 7 was shown graph of function current density to the potential for composite coatings containing WC. The corrosion resistance of composite coatings were compared to the corrosion resistance of the Stellite-6 coating made by the same method with the same parameters of laser power and feed but without WC particles. Comparing the corrosion resistance of each of the surface layers, it was found that the presence of tungsten carbide particles in the coating will increase susceptibility to corrosion.

4. Conclusions

- The presence of carbides in the coating reduce the electrochemical corrosion resistance of the surface layers. This type coatings should be used for products requiring high wear resistance, but not necessarily used in aggressive corrosive environments.
- The addition of WC particles causes the formation of very hard phases: WC, $M_{23}C_6$ and M_7C_3 , which have influence on wear resistance of final product.
- Coating microstructure is similar to the microstructure of sintered carbide, but special attention should be paid to the powder mixing process, because it affects the uneven distribution of carbides in the coating.

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