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MICROSTRUCTURE AND WEAR RESISTANCE OF STELLITE-6/WC METAL MATRIX COMPOSITE COATINGS

Summary

The paper presents the study results of metal matrix composite coatings formed on S355 and B27 steels by laser cladding with powder technology. Powder mixture consisting of cobalt based alloy and tungsten carbides particles was used. The study consisted of production of the coatings using Trumpf TruDisk laser device equipped with 3-stream nozzle powder feeding system. Composite coatings were produced both on laboratory specimens as well as on agricultural tools. The constant value of feed rate equals 460 mm ⊙ min^{-1} and different values of laser beam power (400, 550 and 700 W) have been used. The influence of laser beam power on microstructure, chemical composition and wear resistance on produced coatings have been investigated.
Key words*: laser cladding, microstructure, EDS microanalysis, tungsten carbides, cobalt based alloys*

MIKROSTRUKTURA I ODPORNOŚĆ NA ZUŻYCIE KOMPOZYTOWYCH WARSTW POWIERZCHNIOWYCH STELLITE-6/WC

Streszczenie

Przedstawiono wyniki badań z kompozytowych warstw powierzchniowych wytwarzanych na stalach S355 i B27 przez napawanie laserowe techniką proszkową. Zastosowano mieszaninę proszkową składającą się z proszku stopu na bazie kobaltu i cząstek węglika wolframu. Badanie polegało na wytworzeniu warstw powierzchniowych przy użyciu urządzenia laserowego Trumpf TruDisk wyposażonego w system trójstrumieniowego podawania proszku.Warstwy powierzchniowe wytwarzano zarówno na próbkach laboratoryjnych jak i na narzędziach rolniczych. Zastosowano stałą wartość posuwu wiązki lasera równą 460 mm ⊙ min^{-1} oraz różne wartości mocy wiązki (400, 550 i 700 W). Badano wpływ mocy wiązki lasera na mikrostrukturę, skład chemiczny i odporność na zużycie przez tarcie wytworzonych warstw powierzchniowych.
Słowa kluczowe*: napawanie laserowe, mikrostruktura, mikroanaliza EDS, węgliki wolframu B_4C, stopy kobaltu*

1. Introduction

Reliability of agricultural machinery is largely dependent on the durability of tools installed in them. Exploitation of them usually leads to longer breaks in the cultivation of the soil, which entail economic losses. Work conditions of agricultural tools can be described as difficult, or even extreme. The intensity of wear caused by impact of soil depends mainly on difference in hardness of the friction material and tool material [1, 2]. Parts of agricultural machines are used up predominantly due to the abrasive effects of hard particles of soil on surface layer and as a result of impact loads. Therefore, materials to produce tool which operate in the soil should be characterized by high durability. This requirement meets very small group of materials. These are mainly sintered carbides and steels with boron.

Increasing wear resistance can also be obtained by methods and techniques of surface engineering [3-10], mainly by producing clads with wear-resistant materials. It is important that the cladded coatings should be produced on right place of operating parts. Laser cladding seems to be particularly interesting because of the great possibilities of the laser beam control.

Most of the wear resistance research is based on laboratory apparatus, wherein the abrasive media are materials such as alumina, quartz sand or silicon carbide. These materials cause very rapid wear, but in soil do not occur in pure form. Conditions of laboratory test is different from the real conditions during use of tools in the soil. This paper presents the results of field tests of agricultural tools and metallographic analysis of composite coatings produced on tools by laser cladding technology.

2. Aim and Scope of Research

The aim of this study was to determine relationship between laser beam power, and selected properties of metal matrix composite coatings produced by laser cladding on S355 and B27 steel using powder mixture of Stellite-6 and WC. Microstructure, chemical composition and wear resistance of coatings were investigated.

3. Research Methodology

3.1. Production Conditions of MMC Coatings

Laser cladding process was carried out using a 5-axis LaserCell 3008 from Trumpf company equipped with TruDisk laser with a power rating equal to 1000 W. This device allows to produce coatings, and carry out laser heat treatment on products with complex shape.

Metal matrix composite coatings were produced on S355 low-carbon steel and B27 steel in order to significantly improve properties of its surface layer. Chemical compositions of S355 and B27 steels used are shown in Table 1.

Table 1. Chemical composition of steels used
Tab. 1. Skład chemiczny użytych stali

	C	Si	Mn	P	S	Cr	Mo	Ni	Cu	B	Ti	Fe
S355	0,185	0,128	1,180	0,016	0,002	0,282	0,070	0,135	0,335	0,000	0,015	Base
B27	0,266	0,141	1,267	0,018	0,003	0,406	0,055	0,030	0,267	0,002	0,035	Base

Source: own work / Źródło: opracowanie własne

The powder mixture consisting of 40% of Stellite-6 and 60% of tungsten carbide WC was applied as a material to produce MMC coating. Spherical powder particles of Stellite-6 with a diameter in the range of 25-53 μm, and WC particles with a dimensions in the range of 50-100 μm with irregular shape were used. Morphology of powder mixture is shown in Figure 1.

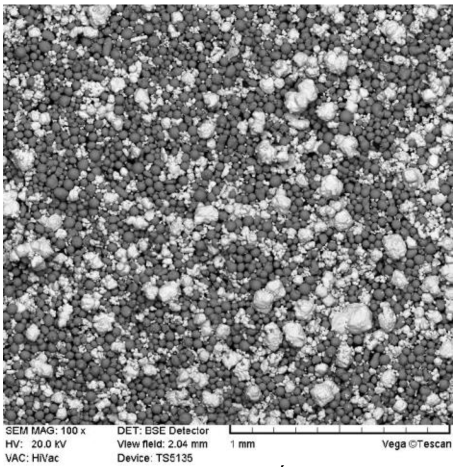

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Fig. 1. Morphology of powder mixture Stellite-6/60%WC
Rys. 1. Morfologia mieszaniny proszkowej Stellit-6/60%WC

Laser cladding was carried out using different powers of laser beam: 400, 550 and 700 W and the same scanning speed which was equal to 460 mm ⊙ min^{-1}. During laser cladding process, laser beam diameter 1,64 mm; 40% overlapping; powder feed rate of 5,12 g ⊙ min^{-1} were applied and distance between head tip, and substrate 12 mm; angle between laser head, and substrate 90°; flow rate of carrier gas (He) and shielding gas (Ar) equal to 8 l ⊙ min^{-1} were used. The schema of production of MMC coating using laser cladding technology is shown in this volume – page 18, Fig. 2 [11].

3.2. Microstructure, chemical composition and wear resistance tests

Metallographic cross- sections were subjected to etching after laser cladding process. For observation of MMC coatings microstructure a solution of 25% HCl and 75% HNO3 was used and subsequently was observed using Neophot 32 microscope with digital camera and VEGA TESCAN 5135 scanning electron microscope (SEM). The point X-ray microanalysis of chemical composition was performed using EDS method by Prism Si(Li) 2000.

Wear resistance tests in laboratory were performed on AMSLER A135 device. Wear process proceeded in dry friction conditions. The system of wear-pair was specimen (plate with MMC coating) – counterspecimen (ring from 100Cr6 steel with a hardness of 64 HRC). Wear tests were performed using rotation speed n = 179 rev ⊙ min^{-1}, a load F = 392 N at time t = 360 minutes. Specimens were measured by weighing after 30, 90, 180, 240 and 360 minutes of friction.

Operational tests were carried out in soil of III class. The stoniness was defined as small. Agricultural tools – coulters – with MMC coatings and without coatings were assembled in a Terrano 6FG Horsch cultivator. Cultivator was driven by T8.390 New Holland tractor with rate in the range of 5-8 km/h. Research results were developed using ATOS II GOM optical scanner by creating a colorful map of wear.

4. Results of Research

All the produced Stellite-6/60%WC MMC coatings were characterized by surface topography which is typical for obtained using high-energy treatment method (laser, plasma, etc.). No defects in the geometrical structure in the form of gas bubbles, porosity or cracks were observed on produced MMC coatings. In the Figure 2 exemplary macroscopic image of Stellite-6/60%WC coating is shown.

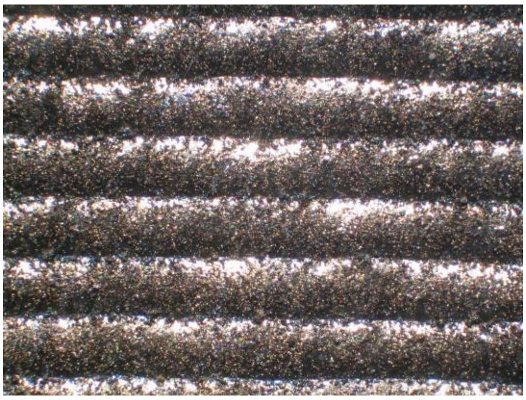

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Fig. 2. Stellite-6/60%WC coating produced by laser cladding
Rys. 2. Warstwa powierzchniowa Stellite-6/60%WC wytworzona metodą napawania laserowego

As a result of laser cladding process the coatings with composite microstructure consisting of primary tungsten carbide particles and Co-based alloy matrix were prepared. Depending on the power of the laser beam, differences in proportions of reinforcing phase and matrix were observed. A characteristic feature of all composite coatings was dendritic microsegregation caused 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.

The greatest heterogeneity of microstructure was observed in the coating produced using maximum laser beam power. Juxtaposition of MMC coating microstructures produced by laser cladding with a powder mixture containing 40% of

Stellite-6 powder and 60% of WC particles was shown in Figure 3. It was found that the higher laser beam power increases the thickness of produced coatings. Increasing the laser beam power, also causes melting of surface of tungsten carbides particles and their shape was changed from the irregular on spherical.

The chemical composition of the Stellite-6/60%WC coating produced using the powder feed rate equal to 5.12 g/min (Figure 4) indicated on presence of $M_{12}C$ phase which is present also on W-C-Co equilibrium phase diagram. On the basic of EDS microanalysis results it can be concluded that on the boundary between carbide and matrix are formed new complex phases in type (Co, W, Cr, $Fe)_{12}C$.

Figure 5 shows the influence of production parameters on the wear resistance under conditions of dry friction. Very large impact on the rapid wear has a high power of laser beam, which caused an intensive mixing of additional material and steel substrate as well as reducing hardness by increasing iron content in coating. The matrix of reduced hardness was less resistant to the micro-cutting process. In the case of coatings produced using laser beam power of 400 W, some WC particles were not well integrated with matrix. It led to the formation of chipping. Coating produced using laser beam power of 550 W were characterized by the best wear resistance. In this layer, particles of WC were well bonded with metal matrix, and the matrix itself did not contain large amounts of iron and did not lose hardness.

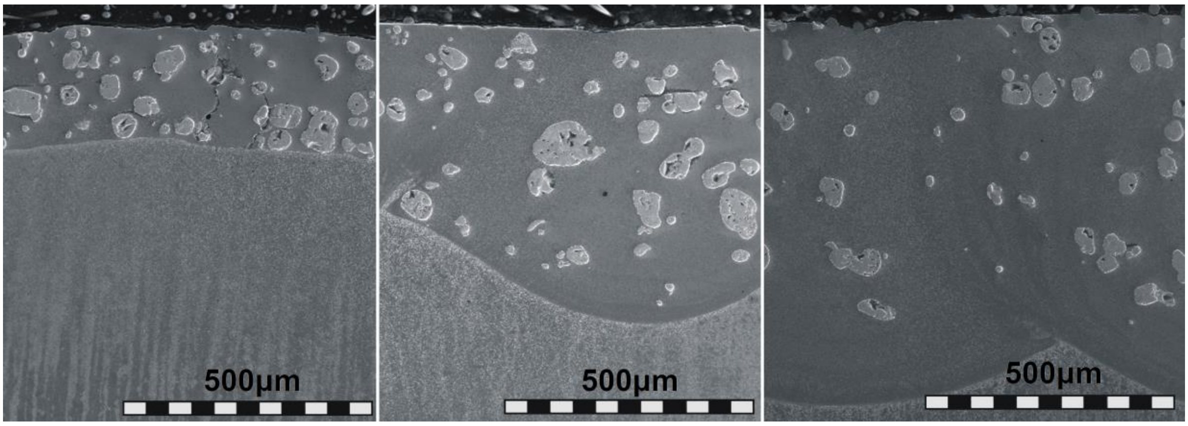

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Fig. 3. Microstructure of MMC Stellite-6/60%WC coating produced using laser beam power of 400 550 and 700 W consecutively

Rys. 3. Mikrostruktura kompozytowych warstw powierzchniowych Stellite-6/60%WC wytwarzanych przy mocy wiązki lasera kolejno 400 550 i 700 W

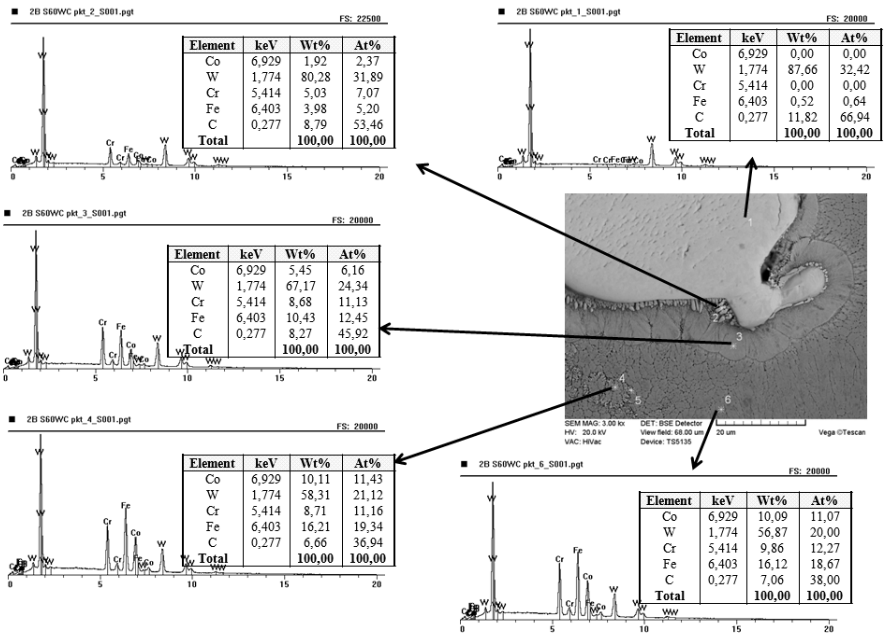

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Fig. 4. Point analysis of chemical composition within carbide-matrix boundary of MMC Stellite-6/60%WC coating prepared using laser beam power of 550 W

Rys. 4. Punktowa analiza składu chemicznego w obrębie granicy węglik-osnowa dla kompozytowej warstwy powierzchniowej Stellite-6/60%WC wytworzonej przy użyciu mocy wiązki lasera 550 W

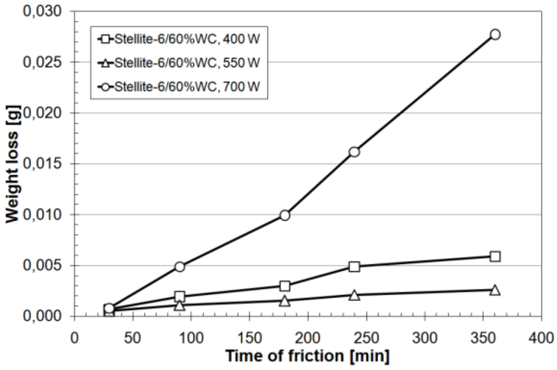

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Fig. 5. Influence of production parameters of MMC coatings on wear resistance under dry friction conditions
Rys. 5. Wpływ parametrów wytwarzania warstw kompozytowych na odporność na zużycie w warunkach tarcia suchego

Figure 6 presents selected series of coulters with MMC coatings. In the figure, 8-a and 8-b, colorful maps of shape change of coulter without coatings and with composite coatings of Stellite-6/60%WC respectively are presented. Additionally each sample was presented as contours applied on contour of the sample before field tests. In places where it was possible, geometric change was marked as a change of colors. The lowest wear was marked with a green color, and continue through yellow, to red, which meant the greatest wear.

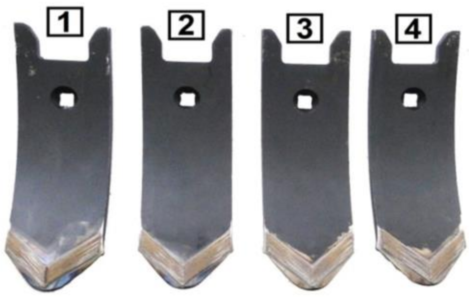

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Fig. 6. Selected series of coulters with MMC Stellite-6/WC coatings
Rys. 6. Wybrana seria redlic z wytworzoną kompozytową warstwą powierzchniową Stellite-6/WC

Creation of hard coating on coulter slowed the process of tool wear. Substrate material was damaged only after removal of MMC coating with tungsten carbide. Figure 7a shows the degree in which agricultural tool has been destroyed by frictional forces in the soil. Sample presented in Figure 7b used-up much less, which was the result of a slow wear of bow section coulter.

5. Summary and Conclusions

Based on results of laboratory and operating tests the following conclusions can be drawn:

1. Coatings are characterized by uniform and dense distribution of reinforcing particles.
2. Tungsten carbide particles were very well bonded with metal matrix. At the border of reinforcing phase and matrix the area of secondary complex carbides was formed as a result of the surface melting of WC particles.
3. In metal matrix, around the WC particles zone with a modified microstructure, microhardness and chemical composition was revealed.
4. Based on results of field tests, it was found that the Stellite-6/WC coatings may increase the durability of agricultural tools.

a)

b)

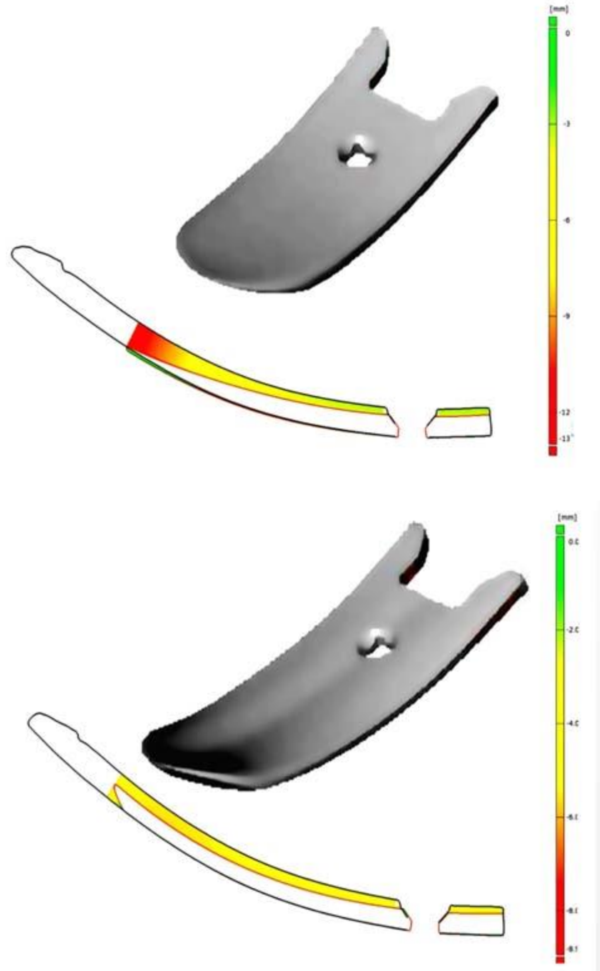

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Fig. 7. CAD models of agricultural tools: a) a tool without MMC coating, b) tool with MMC Stellite-6/WC coating
Rys. 7. Modele CAD narzędzi rolniczych: a) narzędzie bez kompozytowej warstwy powierzchniowej, b) narzędzie z warstwą kompozytową Stellite-6/WC

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