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Co-BASED ALLOY SURFACE LAYERS WITH BORON CARBIDE PARTICLES PRODUCED ON S235 STEEL BY LASER CLADDING METHOD

Summary

The work presents results of study of the surface layers formed during the laser cladding process with powder mixture of Co-based alloy and B_4C particles on S235 steel. The study included production of the surface layers by using laser device equipped with three-stream nozzle powder feeding system. The different feed rate and the same value of laser beam power have been used. The influence of powder morphology on efficiency of laser metal deposition as well as influence of B_4C additive on microhardness, microstructure and chemical composition of produced surface layers have been investigated.
Key words: *laser cladding, microhardness, microstructure, EDS microanalysis, B_4C boron carbide, Co-based alloys*

WARSTWY POWIERZCHNIOWE ZE STOPU KOBALTU ORAZ CZĄSTEK WĘGLIKA BORU WYTWARZANE NA STALI S235 METODĄ NAPAWANIA LASEROWEGO

Streszczenie

W pracy przedstawiono wyniki badań warstw powierzchniowych wytworzonych przez napawanie laserowe mieszaniny proszkowej stopu na bazie kobaltu i cząstek węglika boru B_4C na stali S235. Badania obejmowały wykonanie warstw powierzchniowych przy użyciu urządzenia laserowego wyposażonego w dyszę z trójstrumieniowym systemem podawania proszku. Zastosowano różne prędkości posuwu wiązki lasera przy jednakowej wartości mocy. Stwierdzono, że rodzaj morfologii proszku ma wpływ na wydajność procesu napawania. Określono wpływ dodatku węglika boru na twardość, mikrostrukturę i skład chemiczny wytwarzanych warstw powierzchniowych.
Słowa kluczowe: *napawanie laserowe, mikrotwardość, mikrostruktura, mikroanaliza EDS, węglik boru B_4C, stopy kobaltu*

1. Introduction

Tools and machine parts exploited in direct contact with abrasive media such as rocks, sand, gravel, clay and cultivated soil are exposed to wear and corrosion. In the case of agricultural machinery, this problem affects mainly durability of cultivation tools. On their surface affects not only hard soil particles which cause abrasion, but also rocks that cause impact character pressure. Durability prediction of product exploited in the soil is very difficult due to the complexity of soil medium, its specific physico-chemical and biological properties as well as diverse morphology [1, 2]. So far relationship between properties of materials used for agricultural tools, and their durability in the soil have not been clearly defined. This is due to among others ever-changing operating conditions, which depend on weather, climate, seasons etc. However there are publications in which evaluated legitimacy of specific hard-wearing materials on working elements used in the soil [3]. Such studies allow to obtain reliable information about tools durability under specific operational conditions. Research works aim at significantly increasing durability of agricultural tools, as well as reduce costs associated with cultivation of the soil. Frequent disassembly of worn tools and reassembly of new tools causes cost increase of agricultural treatment but also lowering performance and undesirable downtime.

There are many methods and techniques of surface engineering used to improve the exploitation properties of the surface layers of tools and machine parts. In recent years, there is a lot of interest of surface layers production by welding methods. Both in the country and in the world increasingly applied is powder laser cladding method. This method requires use of laser device equipped with powder feeder and nozzle for dispensing and melting powder with substrate. The essence of method is to produce layer of even thickness which good adjacent to substrate and obtain minimum thickness of heat affected zone. An important advantage of this method is ability to produce surface layers of any chemical composition on product of any shape [3-11].

2. Aim and Scope of Research

The aim of study was to determine relationship between laser beam rate, and surface layer properties produced by laser cladding on S235 steel. Microstructure of weld and heat affected zone, thicknesses as well as chemical composition of prepared surface layers were investigated.

3. Research Methodology

3.1. Conditions for the Production of Surface Layers

Deposition process was carried out using a LASER TRUMPF CELL 3008 equipped with TruDisk 1000 laser. This device allows to production surface layers, and carrying out laser heat treatment on small and medium-size products about complex shape. This is possible using the 5-axis laser head.

Composite surface layers were produced on S235 low-carbon steel in order to significantly improve its properties. This is a low-cost structural steel for general use. Chemical composition os S235 steel is shown in Table 1. The powder mixture consisting of 90% Stellite-6 and 10% boron carbide

B4C was applied as a coating material. Spherical powder particles of Stellite-6 with a diameter in the range of 25-53 microns, and B4C particles with a diameter in the range of 40-60 microns and irregular shape were used. Morphology of powder mixture is shown in Figure 1.

Table 1. Chemical composition of S235 steel
Tab. 1. Skład chemiczny stali S235

Element	**C**	**Mn**	**P**	**S**	**N**	**Fe**
wt %	0,17	1,40	0,035	0,035	0,009	base

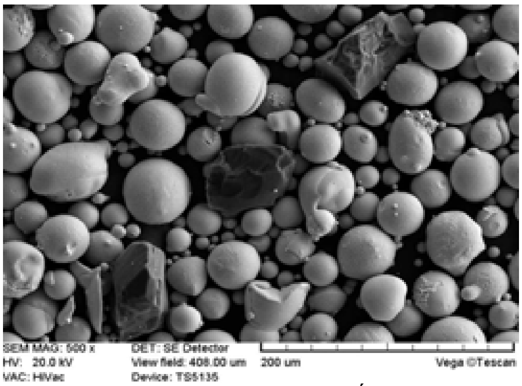

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Fig. 1. Morphology of powder mixture Stellite-6 + 10% B_4C
Rys. 1. Morfologia mieszaniny proszkowej Stellit-6 + 10% B_4C

Laser cladding was carried out using power laser beam of 400 W. Variable feed rates of laser beam about following values: 360, 390, 420, 450, 470, 510, 550, 590, 630 mm/min was applied. Important parameters applied during laser cladding process were also: laser beam diameter 1.642 mm; 35% overlapping; powder feed rate of 3.2 $g \cdot min^{-1}$; 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 5 $l \cdot min^{-1}$. Three-streamed powder feeding system put appropriate quantity of powder at one point located in laser beam. Schema of powder laser cladding using powder mixture with carbide particles is shown in Figure 2.

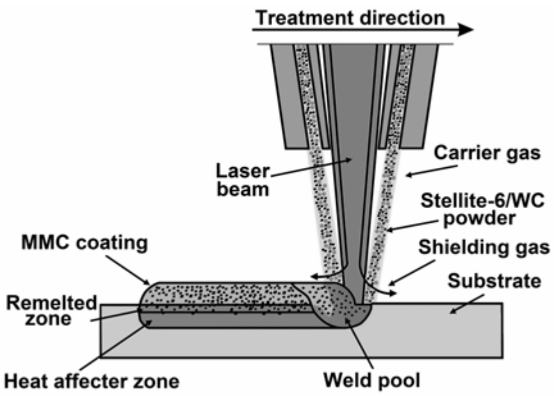

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Fig. 2. Schema of powder laser cladding deposition Stellite-6 + B_4C
Rys. 2. Schemat procesu proszkowego napawania laserowego proszkiem Stellit-6 + B_4C

Reduce amount of powder feed rate of Stellite-6 + B4C in relation to amount Stellite-6 was necessary. B4C powder morphology (sharp edges) in combination with spherical particles of Stellite-6 powder resulted in formation of irregular slipping layers and blocking powder particles in feeder.

3.2. Microstructure, Thickness, Hardness and Chemical Composition

After laser cladding process were prepared metallographic cross section which was subjected twice etching. To visualize substrate microstructure was used 2% nital, while, to show surface layer microstructure was used solution of 25% HCl and 75% HNO3. Microstructure was observed using Neophot 32 microscope with digital video recording and VEGA TESCAN 5135 scanning electron microscope.

Microhardness studies on cross-section of layer from surface to the substrate was carried out using PMT-3 Vickers microhardness tester according to PN-EN ISO 6507-1:1999, using HV 0.05 scale.

The linear X-ray microanalysis of chemical composition was performed using Prism Si(Li) 2000 EDS microanalyser.

4. Results of Research

Figure 3 shows surface layer condition after laser cladding. As a result of laser cladding, surface layers characterized by dendritic microstructure and different thicknesses were prepared. It was found that lower feed rate of laser beam cause pores and cracks in surface layers extending from surface to the steel substrate.

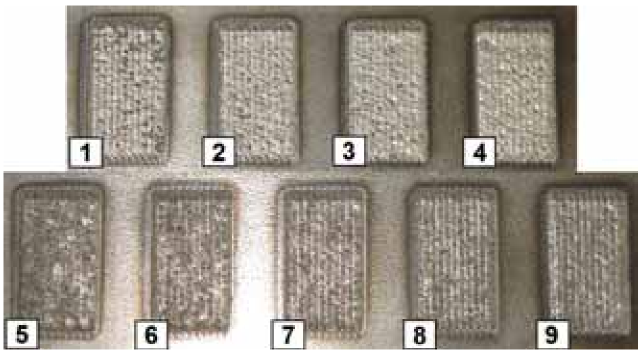

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Fig. 3. Surface layers conditions formed by powder laser cladding Stellite-6 + 10% B4C by laser beam power of 400 W, and feed rate: 1) 360 $mm \cdot min^{-1}$, 2) 390 $mm \cdot min^{-1}$, 3) 420 $mm \cdot min^{-1}$, 4) 450 $mm \cdot min^{-1}$, 5) 470 $mm \cdot min^{-1}$, 6) 510 $mm \cdot min^{-1}$, 7) 550 $mm \cdot min^{-1}$, 8) 590 $mm \cdot min^{-1}$, 9) 630 $mm \cdot min^{-1}$
Rys. 3. Stan warstwy powierzchniowej wytworzonej przez laserowe napawanie proszku Stellit-6 + 10% B_4C wiązką lasera o mocy 400 W i prędkości posuwu: 1) 360 $mm \cdot min^{-1}$, 2) 390 $mm \cdot min^{-1}$, 3) 420 $mm \cdot min^{-1}$, 4) 450 $mm \cdot min^{-1}$, 5) 470 $mm \cdot min^{-1}$, 6) 510 $mm \cdot min^{-1}$, 7) 550 $mm \cdot min^{-1}$, 8) 590 $mm \cdot min^{-1}$, 9) 630 $mm \cdot min^{-1}$

Along with increasing feed rate, the number and size of pores and cracks in cladding layer systematically decreases (Fig. 4).

With addition of boron carbide particles to Stellite-6 powder and diversity of laser beam feed rate, substantial changes in the microstructure of weld layer were obtained. Comparison of classical microstructure of Stellite-6 with microstructure of layers produced by laser cladding (Fig. 5) shows that changes are based mainly on dispersion, shape and distribution of dendrites. Both feed rate of laser beam and differences in addition of boron carbide to Stellite-6 lead to microstructural changes.

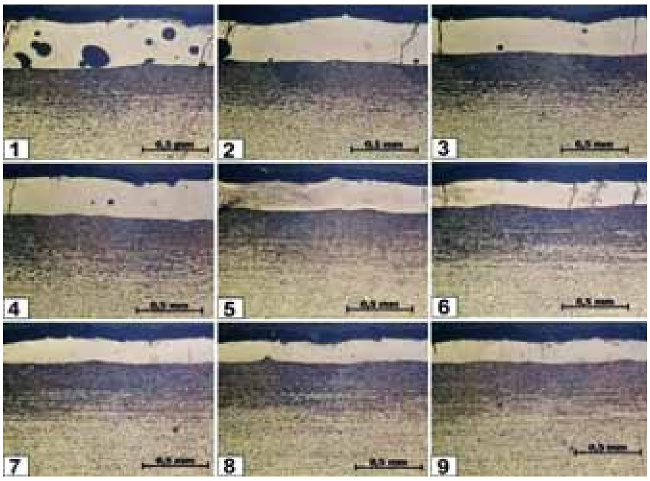

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Fig. 4. Surface layers formed by powder laser cladding Stellite-6 + 10% B4C by laser beam power of 400 W, and feed rate: 1) 360 mm·min^{-1}, 2) 390 mm·min^{-1}, 3) 420 mm·min^{-1}, 4) 450 mm·min^{-1}, 5) 470 mm·min^{-1}, 6) 510 mm·min^{-1}, 7) 550 mm·min^{-1}, 8) 590 mm·min^{-1}, 9) 630 mm·min^{-1}

Rys. 4. Warstwy powierzchniowe wytworzone przez laserowe napawanie proszku Stellit-6 + 10% B_4C wiązką lasera o mocy 400 W i prędkości posuwu: 1) 360 mm·min^{-1}, 2) 390 mm·min^{-1}, 3) 420 mm·min^{-1}, 4) 450 mm·min^{-1}, 5) 470 mm·min^{-1}, 6) 510 mm·min^{-1}, 7) 550 mm·min^{-1}, 8) 590 mm·min^{-1}, 9) 630 mm·min^{-1}

As a result of thickness measuring of produced layers (Table 2), it was found that the total thickness of layer and heat affected zone decreased slightly with increasing feed rate. It can be assumed that total thickness of two zones of surface layer is comparable, and effect of feed rate is mainly characterized by changing thickness ratio of clad zone and heat affected zone. Thickness decrease of clad layer causes more heat transfer to substrate. Figure 6a shows influence of feed rate on clad layer thickness, which has been steadily decreasing, and Figure 6b, shows influence of the same parameter on heat affected zone thickness, which is steadily increasing. As can be seen, at the higher feed rates, thickness of heat affected zone is stabilized at about 480 um. Understanding reasons of thickness distribution in both zones of surface layer (depending on feed rate of laser beam) requires further studies.

Table 2. Thickness of surface layers produced by powder laser cladding Stellite-6 + 10% B4C

Tab. 2. Grubość warstw wytwarzanych przez laserowe napawanie proszkiem Stellit-6 + 10% B_4C

No.	Feed rate [mm/min]	Cladding zone [µm]	Heat affected zone [µm]	Total thickness of layer [µm]
1	360	390	380	770
2	390	340	410	750
3	420	300	450	750
4	450	290	460	750
5	470	240	470	710
6	510	210	480	690
7	550	200	480	680
8	590	190	480	670
9	630	170	480	650

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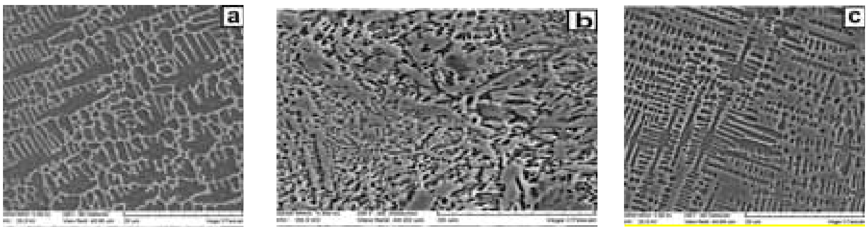

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Fig. 5. Microstructure: a) Stellite-6 without modification, b) Stellite-6 + 10% B4C, laser beam power of 400 W, feed rate of 450 mm·min^{-1}, c) Stellite-6 + B4C, laser beam power of 400 W, feed rate of 630 mm·min^{-1}

Rys. 5. Mikrostruktura: a) Stellite-6 bez modyfikacji, b) Stellite-6 + 10% B_4C, moc wiązki lasera 400 W, posuw 450 mm·min^{-1}, c) Stellite-6 + B_4C, moc wiązki lasera 400 W, posuw 630 mm·min^{-1}

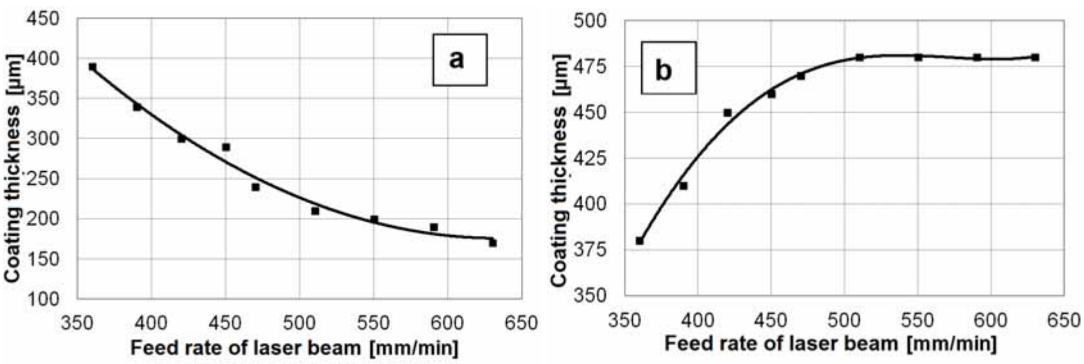

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Fig. 6. Dependency graph of coating thickness on feed rate laser beam (a) and dependency graph of the heat affected zone (HAZ) on feed rate laser beam (b)

Rys. 6. Wykres zależności grubości warstwy napawanej od prędkości posuwu (a) oraz wykres zależności grubości strefy wpływu ciepła od prędkości posuwu (b)

Laser cladding surface layers produced from Stellite-6 + 10% B4C powder has a large value of microhardness, about 1300 HV 0.05. Microhardness gradually decreases with increasing distance from the surface (heat affected zone - 600 HV 0.05; core - about 200 HV 0.05). Figure 7a shows layer microhardness profile produced by laser cladding with feed rate 450 mm·min^{-1}. Figure 7b shows microhardness profile for the smallest layer thickness (feed rate 630 mm·min^{-1}), while Figure 7c shows microhardness profile of Stellite-6 layer without boron carbides addition. It can be seen that layers performed at lower feed rates have higher hardness, and that addition of boron carbide greatly increases hardness value.

a)
b)
c)

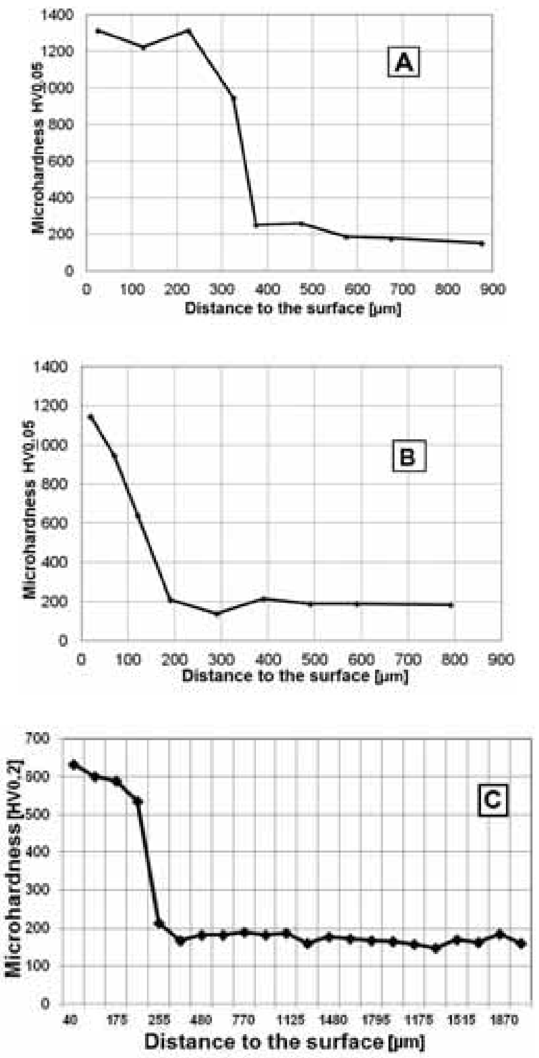

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Fig. 7. Microhardness graph of layer after laser cladding with feed rate of 450 mm·min^{-1} and laser beam power 400 W (a), with feed rate of 630 mm·min^{-1} and laser beam power 400 W (b), and for layer of Stellite-6 without addition of boron carbide (c)

Rys. 7. Wykresy mikrotwardości warstw po napawaniu laserowym z prędkością posuwu 450 mm·min^{-1} (a), z prędkością posuwu 630 mm·min^{-1} (b), oraz dla warstwy Stellitu-6 bez dodatku węglika boru (c)

Figure 8 shows chemical composition results of layer produced by laser cladding with Stellite-6 + 10% B4C powder using feed speed 630 mm·min^{-1}. EDS X-ray microanalysis showed lack of boron and carbide atoms in clad layer and also revealed the presence of chemical elements contained in Stellite-6 powder. On the basis of distribution graph analysis of individual elements in cross-section (in the direction shown in Figure 8), it was found that content of Co, W and Cr in surface layer is uniform throughout its thickness, and iron content increases in closer to substrate. It was found high Co content in substrate and increased Fe content in clad layer on the border layer-substrate. It proves about mixed clad layer with substrate during laser cladding process (detail D in Figure 8). For samples produced at different feed rates, content of elements in clad layer was changed.

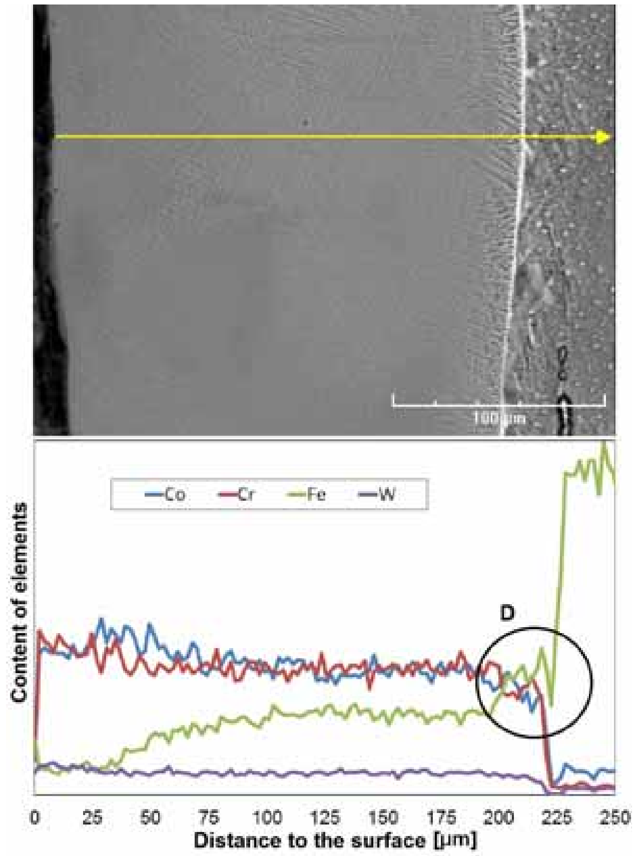

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Fig. 8. X-ray microanalysis results of layer after laser cladding with feed rate of 630 mm·min^{-1} and laser beam power 400 W

Rys. 8. Wyniki mikroanalizy rentgenowskiej EDS warstwy po napawaniu laserowym z prędkością 630 mm·min^{-1} i mocą wiązki lasera 400 W

5. Summary and Conclusions

Through the laser cladding with Stellite-6 + B4C the surface layers which are characterized by high dendrites dispersion were prepared. Dendrites shape and their arrangement are different in relation to layers produced in mixture without B4C. It can be concluded that microstructure changes are caused by dissolution of boron carbide during laser cladding process and enriching the surface layer with boron. Microstructure changes also increase microhardness, as evidenced by the microhardness profiles comparison between layer formed using pure Stellite-6 and with addition of 10% B4C.

Stellite-6 + B4C layers are characterized by high microhardness reaching a value of 1300 HV 0.05. It was found double increase of microhardness value. With the increase of laser beam feed rate, reduction of amount and size of porosity in produced layers were observed.

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