Morphology studies of the cobalt base clad layers produced by laser technology

Badania morfologii napawanej laserowo warstwy na bazie kobaltu

ABSTRACT

Cobalt base laser cladding layers on the exhaust valve head face have been investigated. The obtained microstructure was affected by process parameters and tracks geometry. The performance of the layers was evaluated by microscopic examination and micro hardness measurements.

INTRODUCTION

The severe work conditions of the marine diesel engine require a special treatment of the valve surface. This part is exposed both to dynamic loads resulting from combustion pressures and variable high temperatures. Additionally, highly corrosive environment strongly influences the service life of the valves. The typical damages of exhaust valve seat are the following:

- Tightness loss due to corrosion pits caused by exhaust gases
- Burnt-out of head plate rims due to the flow of hot gases
- Cracks, scratches and splinters caused by the wear of the seat face top layer.

Laser cladding is developed to improve the surface wear and corrosion resistance properties and to provide longer and more reliable time of work. Among materials, which can improve surface properties, there are cobalt base alloys, which offer excellent high temperature corrosion resistance and attractive mechanical properties. The coating are produced by laser cladding which provide dense material in the form of fine layers, well adhered to the base by surface melting. The higher solidification rate may induce fine microstructure. Various studies have been performed on the most commonly used hard facing materials, called stellites. Some of them emphasize the influence of carbide on abrasive wear resistance and some examine the influence of alloying elements [1,2,3,7].

STRESZCZENIE

Przedmiotem badań były utwardzające warstwy wykonane na przylgni zaworów wydechowych silnika spalinowego. Materiał podłoża to stal H10S2M (Tablica 1). Zastosowano technologię napawania laserowego proszków na bazie kobaltu. Proszki różniły się jedynie zawartością wolframu i zawierały odpowiednio 4,9 (1606), 5,3 (PG5218) i 9 wg% (16012) tego pierwiastka. Parametry napawania były jednakowe dla wszystkich proszków i zestawiono je w tablicy 2. Otrzymane warstwy różniły się twardością na powierzchni a także mikrotwardością na przekroju warstwy (Rys. 2). Najwyższą twardością charakteryzowała się warstwa wykonana z proszku o najwyższej zawartości wolframu. Zmienność twardości na przekroju należy wiązać ze zróżnicowaniem struktury spowodowaną technologią nakładania. Mikrostruktury otrzymane na powierzchni napoiny są podobne dla wszystkich rodzajów proszków. Jednak na granicy napoina/stal obserwowane struktury są zróżnicowane (Rys. 3 – 8). Rozkład pierwiastków w wierzchniej warstwie napoiny generalnie jest równomierny, jakkolwiek obserwuje się pewną segregację wolframu, kobaltu i chromu (Rys. 9).

EXPERIMANTAL

The substrate was the exhaust valve made as an A-R-H10S2M steel forging and its chemical composition is listed in Table 1. This steel is corresponding with a X40CrSiMo10-2 steel. The valve face underwent turning and surfacing by laser technique. Cladding was conducted with a high power diode laser HDPL ROFIN SINAR DL 020 with generated beam power of 2,3 kW. The powder was delivered straight to the melt pool. The parameters of the process are shown in Table 2. The subsequent laser tracks were overlapped by 30 ÷ 40%. In this paper we concentrate on the three new experimental cobalt base powders by CASTOLIN. That powders contents as a main elements chromium (28,8-29,7%), nickel (2,0-2,2%), iron (about 2%), carbon

Table 1. Chemical composition of the steel H10S2M [wt %]

Tablica 1. Skład chemiczny stali H10S2M [wg%]

Steel	C	Cr	Mn	Ni	Si	Mo	P	S
According to analyse	0,374	9,34	0,402	0,344	2,46	0,822	0,0162	0,001
PN-71/H-86022	0,35÷0,45	9÷10,5	max 0,7	max 0,5	1,9÷2,6	0,7÷0,9	max 0,035	max 0,030

Table 2. The laser cladding parameters for processing valve seat made of H10S2M steel

Tablica 2. Parametry napawania laserowego przylgni zaworów wykonanych ze stali H10S2M

Layer	Laser power [kW]	Laser scanning rate [m/min]	Powder feeding rate [g/min]	Track thickness [mm]	Track width [mm]
First layer – two tracks	1,0-1,2	0,20	5,0	1,0-1,2	5,5-6,0
Second and third layer – two tracks for each one	1,1-1,2	0,20	5,0	1,3-1,5	6,0-6,5

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Fig. 1. Cladding process without preheating; the crack of the layer is observed.
Rys. 1 Proces napawania bez wstępnego podgrzania; obserwuje się pęknięcie napoiny

(1,2-1,55%), tungsten and other like molybdenum and silicon in smaller amount. The most important difference between that powders are different amounts of tungsten: 4,9 %- powder 1606; 5,3% - powder PG5218 and 9,0% - powder 16012. Before cladding preheating above 200 $_o$C was necessary to provide clad layers without cracks (Fig.1.).

After cladding, the surface was machined as to obtain proper geometry. In order to conduct further investigation the valve was cut perpendicular to the cladding layer and it was characterized by an optical and scanning electron microscopy (SEM). Micro hardness of the specimens was measured by a PMT-3 hardness tester. The concentration and distribution of the alloying elements were determined using EDS analysis.

RESULTS

The Vickers number hardness obtained after laser cladding on the outer layers were variable in the range from 41HRC (402 HV30) to 46,5HRC (471 HV30) and were higher than average hardness original heat-treated steel, which was 283 HV30. However, this information, which is suitable for users, does not allow to estimate how the presence of many tracks influence on clad layer properties. The effect of multilayer deposition on the hardness value was evaluated by measuring hardness profile along the cross-section from the surface to the clad/steel interface, (Fig.2). This profile showed strong connection between chemical composition of the powder which was used to produce clad layer and average hardness. For the clad produced from 16012 (9,0% W) hardness reached the highest values, but the range of variability is from 500 to 730 HV0,2. For the clads produced from 1606 powder (4,9 %W) and PG5218 (5,3% W) the results are similar and the range of variability is from 350 –650 HV0,2 for 1606 powder and from 420-600 HV0,2 for PG5218 powder. Because the powders differed in the tungsten contains thus its influence on hardness seemed to be clear. The unstable hardness profile is the result of cladding technology, which means multilayer deposition – many trucks for each sublayer.

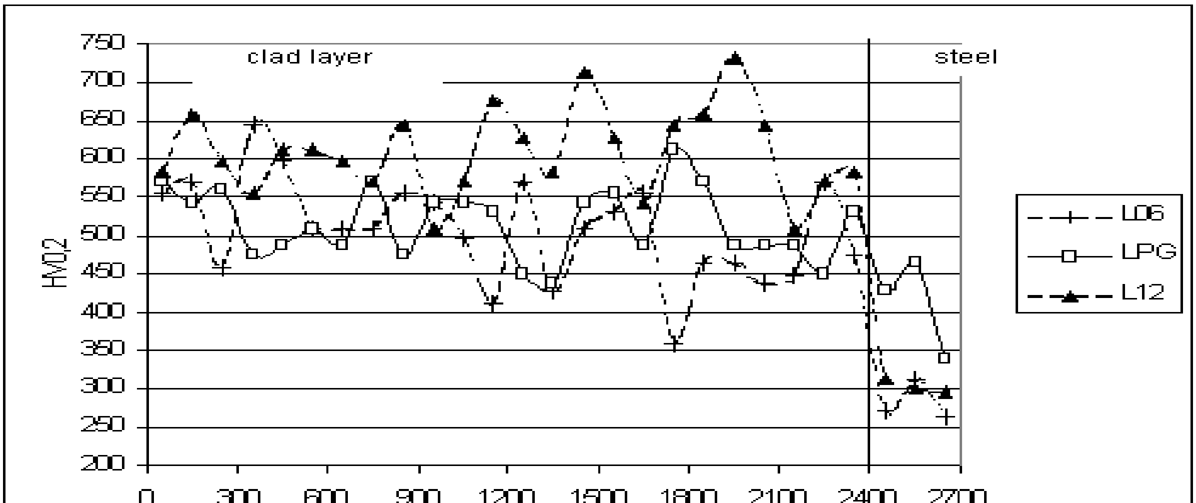

Fig. 2. Micro hardness profile of cross-section specimen from the top to the steel/clad interface. L06 – clad layer made of the powder 1606; LPG - clad layer made of the powder PG5218; L12 - clad layer made of the powder 16012
Rys. 2. Wykres mikrotwardości, prostopadle do przekroju, od powierzchni napoiny do granicy napoina/stal. L06 – napoina wykonana z proszku 1606; LPG – napoina wykonana z proszku 16012

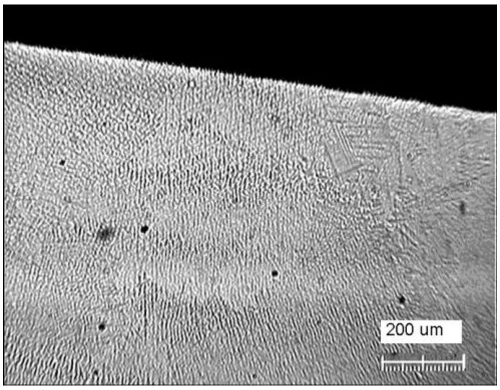

Fig. 3. The top layer of the clad made of 1606 powder

Rys.3. Warstwa wierzchnia napoiny wykonanej z proszku 1606

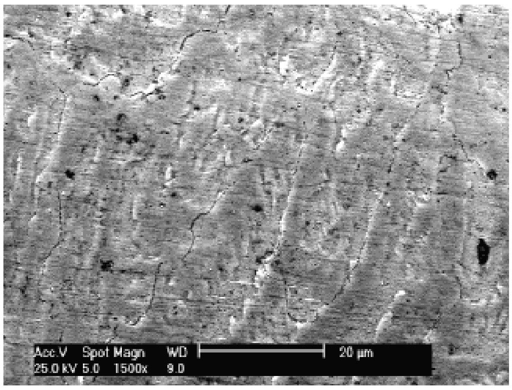

Fig. 4. The top layer of the clad made of 1606 powder

Rys. 4. Warstwa wierzchnia napoiny wykonanej z proszku 1606

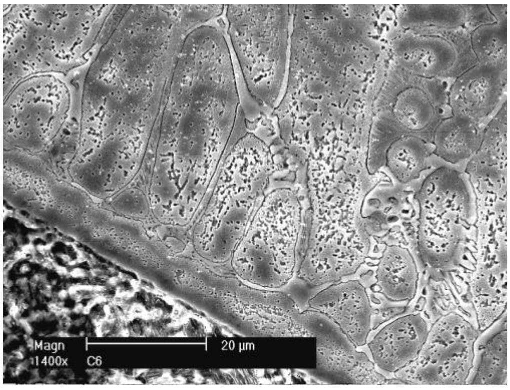

Fig. 5. The clad/steel interface. Powder 1606

Rys. 5. Granica napoina/stal. Proszek 1606

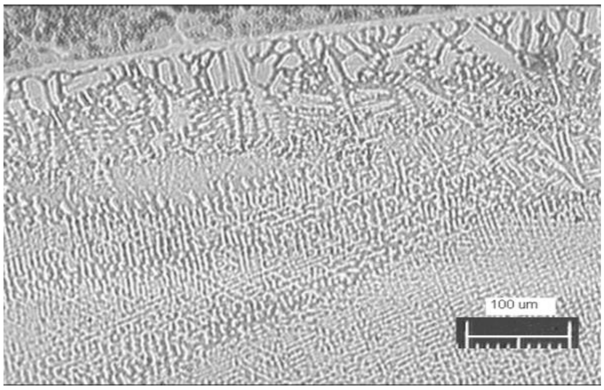

Fig.6. The clad/steel interface. Powder PG5218

Rys.6. Granica napoina/stal. Proszek PG5218

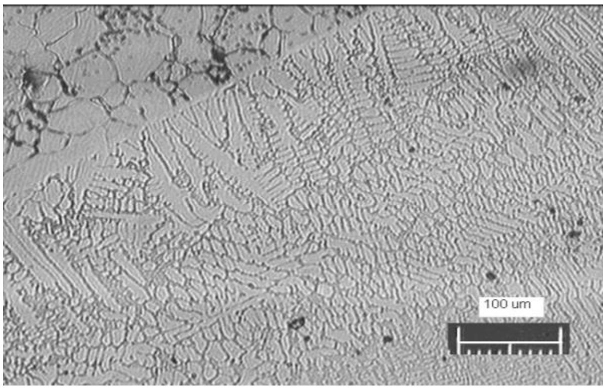

Fig.7. The clad steel interface. Powder 16012

Rys. 7. Granica napoina/stal. Proszek 16012

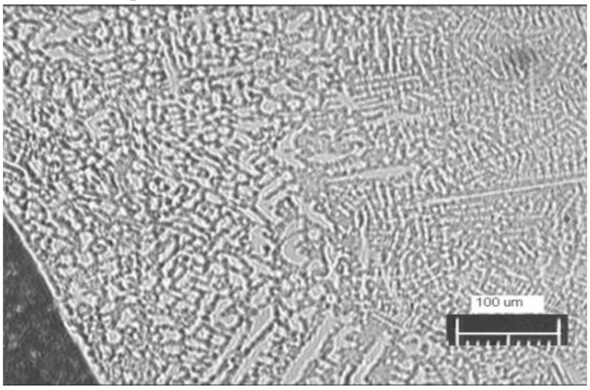

Fig. 8. The clad steel interface. Powder 16012

Rys .8. Granica napoina/stal. Proszek 16012

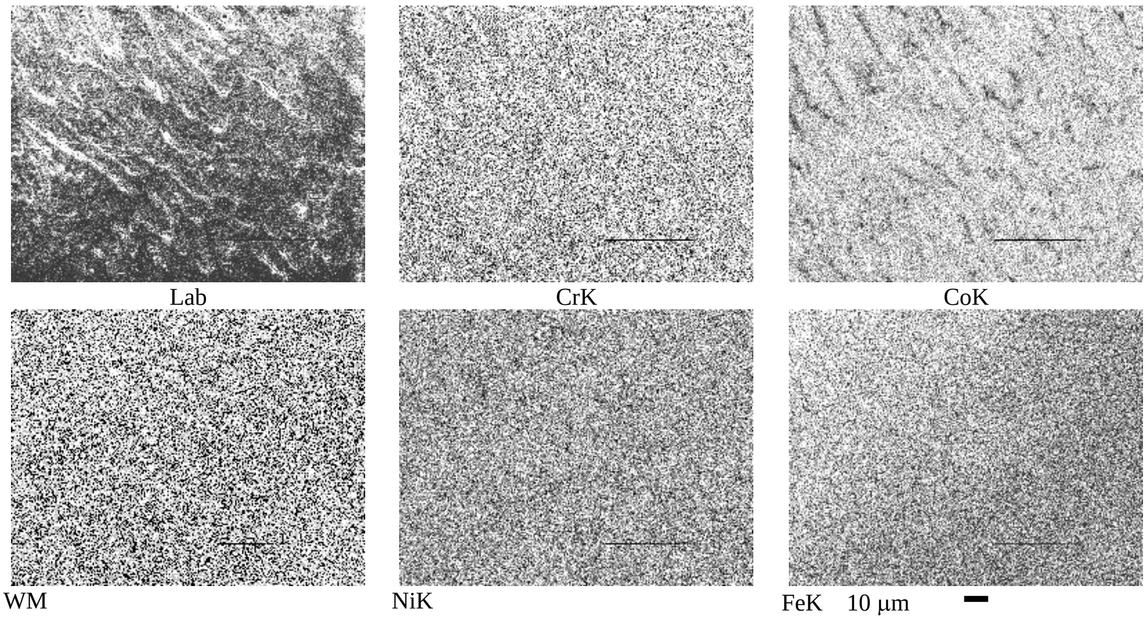

Fig. 9. EDS analysis for the top layer of the clad made of the powder 1606; kV 30, 850x

Rys.9. Analiza EDS warstwy wierzchniej napoiny wykonanej z proszku 16006; kV 30, 850x

MICROSTRUCTURE

A typical surface welding solidification structures were observed in deposited layers. The micro structural study was performed on the cross section of the clad passes. After metallographical preparation, the cross-sections were examined by an optical microscope.

The laser cladded coatings were built up by successively overlapping tracks. Part of the material from the first track melts as the second deposits. Also the heat of a process may influence on the structure [2]. This causes the overlapping zone with the different structure. The metallographic investigation shows that the clad layers do not have a uniform microstructure in both meanings: depending on the type of the powder used, and depending on the distance from the surface of layer. The top layers present a typical coarse dendritic structure (Fig. 3) and these structures are very similar to each sort of layer.

More detailed observations of the top layer demonstrate cracks like looking objects which were situated along the dendrite boundary. They seemed to be a phase, which was destroyed during etching (Fig. 4).

Near the clad/steel interface observed structures are different for different type of powders and also for different region of the clads (Fig. 5 - 8). The observed differences in the structure can be connected with the hardness number and concentration as well as distribution of the alloying elements. The distribution of elements in the top layer generally uniform, however, cobalt and partially tungsten and chromium segregation are observed (Fig. 9).

DISCUSSION

Various regions of the clad are characterized by different morphology, which is connected with different solidification rates and with the heat influence during the successive steps of the layer processing. The produced microstructures exhibit a planar interface followed by the columnar and dendritic region (Fig 5 - 8). The fine dendritic regions are alternated with coarser columnar and cellular areas which correspond to the regions where overlappings of tracks occur (Fig 6). The external parts were characterized by the dendrites and interdendritic eutectics while the internal zones, close to the steel substrate, presented the faced dendrites. The structures of the outer layers were the results of the process of the melt pool formation and solidification. The laser beam heated and melted the powder stream and at the same time, a thin layer of steel was also melted forming the molten pool together with the delivered powder. When the laser moved away, the molten zone started to solidify [4 - 6]. Cobalt rich phase was the first one to become solid in the dendrite form. The remaining liquid was enriched with other elements like chromium, tungsten or carbon and the eutectic structure formed in the interdendritic regions (Fig. 9).

The non-uniform hardness across the coating was connected with the structure changes. Results of hardness measurement (Fig. 2) show the regular changes across the layer from the outer to the internal part of the clad. These changes could be the results of the cladding technology. The clad layer consisted of three sublayers with two tracks for each one. The subsequent laser tracks were overlapped by 30 ÷ 40%. The successive track provided the heat input to the previous track or sublayer and led to the structure changes. However the hardness of the clad layers were higher than for original material which was useful for valve application.

CONCLUSIONS

The performed investigations led to the following conclusion:

- The laser cladding technology is a new good solution for hardening valve head faces.
- To guaranty the good quality of the layers preheating before laser cladding is necessary
- The obtained layers present good fusion bonding to the steel, lack of the cracks and porosity and little distortion of materials produced by this process.
- The HAZ zone is relatively small and its influence on valve properties is limited.
- The microstructure of the clad layer depends on the distance from the base material.

REFERENCES

[1] J.L.De Mol Van Otterloo, J.Th.M. De Hosson; Microstructural features and mechanical properties of cobalt-based laser coating; *Acta Materalia*, vol. 45, no .3, 1997

[2] A.S.C. d`Oliveira, R. Vilar, C.G. Feder; High temperature behaviour of plasma transferred arc and laser Co-based alloy coatings; *Applied Surface Science* 201(2002)

[3] A.S.C. d`Oliveira, P.S.C.P. da Silva, R.M.C. Vilar; Microstructural features of consecutive layers of Stellite 6 deposited by laser cladding; *Surface and Coatings Technology* 153 (2002)

[4] Yongqiang Yang, H.C. Man; Microstructure evolution of laser clad layers of W-C-Co alloy powders; *Surface and Coatings Technology* 132 (2000)

[5] Yongqiang Yang; Microstructure and properties of laser- clad high temperature wear-resistant alloys; *Applied Surface Science* 140 (1999)

[6] Minling Zhong, Wenjin Liu, Kefu Yao, Jean-Claude Goussain, Cecile Mayer, Ahim Becker; Microstructural evolution in high power laser cladding of Stellite 6+WC layers; *Surface and Coatings Technology* 157 (2002)

[7] M. Riabkina-Fishman, J. Zahavi; Laser alloying and cladding for improving surface properties; *Applied Surface Science* 106 (1996)

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