STUDY OF THE STRUCTURE AND MECHANICAL PROPERTIES OF NICRBSI COATINGS PREPARED BY LASER BEAM CLADDING

Zita IŽDINSKÁ[1], Ahmed NASHER[1], Karol IŽDINSKÝ[2]

[1]-Institute of Technologies and Materials, Faculty of Mechanical Engineering, Slovak University of Technology in Bratislava, Pionierska 15, 831 02 Bratislava, Slovak Republic,
zita.izdinska@stuba.sk
[2] Institute of Materials and Machine Mechanics of Slovak Academy of Sciences, Račianska 75, 83102 Bratislava, Slovak Republic

ABSTRACT

In this work, the influence of processing conditions on the microstructure and abrasive wear behavior of a NiCrBSi laser clad coating is analyzed. The powder was applied onto a mild steel substrate (Fe–0.17% C) by different laser powers and cladding speeds, providing 0.7 – 1.2 mm thick coatings. EDX analysis reveals the influence of cladding speed on the dilution of iron from the substrate into the coating. Higher iron content matches with lower hardness and wear resistance of appropriate coatings. Results obtained indicate that laser cladding is a suitable technique for manufacturing NiCrBSi abrasive wear coatings, and that it is possible to determine the correct parameters in order to optimize the tribological behavior of these coatings.

KEYWORDS: NiCrBSi powder, laser cladding; wear resistance, pin on disc test

INTRODUCTION

Nickel-based alloys have a unique combination of properties that enables them to be used in a variety of special purpose applications. In particular, the Ni–Cr–B–Si–C colmonoy alloys provide adhesive wear and corrosion resistance at ambient and high temperatures. Because of the boride and carbide dispersions within their microstructures, these Ni-boride-based alloys also exhibit excellent resistance to abrasive wear [1]. Therefore, NiCrBSi coatings are widely employed to improve the quality of components whose surface is subjected to severe tribological conditions.

Laser cladding techniques, widely recognized as an alternative to flame spraying for some applications, enables the production of dense coatings, metallurgically bonded to the base material, with minimum dilution of the clad layer [2], due to well controlled conditions. However, it is well known that the processing techniques (and also the processing parameters) can affect the microstructure of the coatings, and that dramatic changes can be observed within coatings of the same alloy when processed in different ways. In general, the drastic solidification conditions normally achieved, result in microstructural refinement and in the partial or total dissolution of second phase reinforcement particles [3]. These microstructural changes lead to modifications in the mechanical properties of the material and, consequently, to modifications of its wear behavior.
In the present work, a comparison of the abrasive wear behavior of NiCrBSi coatings prepared by various laser beam parameters is made with the aim of establishing the relationship between the tribological response of the material and the structure that results from different deposition conditions.

EXPERIMENTAL

In laser surface cladding the powder intercepts the laser beam at the same time as the substrate surface, thus causing both to melt and the powder to become deposited on the base material. The powder is introduced into the beam by means of a suitable feed device. The laser used in this study was a CO_2 Ferranti Photonick AF8 Fust Axial Flow laser operating at a power setting of 3.5 and 4.3 kW. All coatings were clad in collaboration with the First welding company, Inc.

The composition of NP 60 powder, (a product of the Welding Research Institute in Bratislava, used to form the coating, is indicated in Table 1. The powder was injected into the nozzle by means of argon gas at a rate of 9 l/min, which transported it from the dosing unit. Another stream of the same gas was emitted through the nozzle at a rate of 15 l/min in order to avoid surface oxidation and to preserve the laser optics.

Tab.1 Chemical composition of the powder

Content (wt. %)	Ni	C	Si	B	Fe	Cr
NP 60	Bal	0,6	5	3,9	5	16

The powder was cladded on 120x100x10 mm^3 mild steel plates (0.17%C, 0.007%N, 0.045%P, 0.045%S) in the form of successive weld passes. Similarly prepared laser claddings were used for further investigations. They differ from each other in the laser beam parameters used, particularly the power of the laser beam and the beam scanning speed. Laser beam cladding parameters and specimen designations are given in Table 2.

Tab.2 Laser beam cladding parameters

Specimen designation	Laser beam power	Cladding speed
3,5/3	3.5 kW	3 mm/s
3,5/5		5 mm/s
3,5/7		7 mm/s
3,5/10		10 mm/s
4,3/5	4.3 kW	5 mm/s
4,3/7		7 mm/s
4,3/10		10 mm/s

The effect of the different parameters of the laser cladding on the coating structure was studied on as-received specimens. Standard metallographic procedures, based on light microscopy methods were used. Coatings were observed in longitudinal and transversal views with particular attention paid to the bonding at the coating substrate interface.

Microstructural studies were conducted using scanning electron microscopy (SEM) observations using a JEOL 5310 electron microscope. A corresponding energy-dispersive X-ray analysis (EDX) was applied for semi-quantitative chemical analysis, using a Kevex Delta class IV spectrometer. Due to the high absorption of X-rays of B and C, chemical composition changes in the deposited coatings were evaluated on the base of varied Fe, Ni, Cr, and Si contents.

Vickers microhardness measurements were performed on a Future Tech, fully automated microhardness tester FM-ARS 9000, with a 100 g load providing vertical hardness profile from the coating surface to the substrate. Tribological properties were evaluated by pin-on-disc wear tests in vertical configuration on flat-ended cylinders with a diameter of 9 mm cut out from the coated plate. All tests were carried out with a pin load 6.125 N on a track of 146 m. Abrasive paper with SiC grains with granularity of 220 micrometers was used as an abradant. The wear was evaluated by measurement of the weight loss of the material. The principle of the test is schematically presented in Fig. 1.

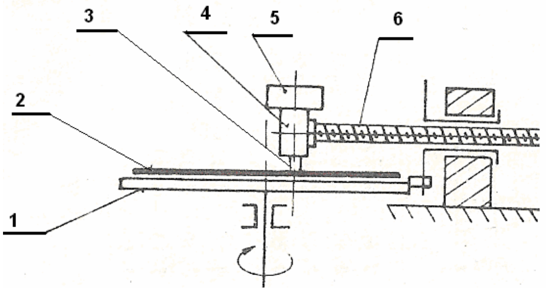

Fig.1 Schematic view of the pin-on-disc testing machine 1 - board, 2 - abrasive paper, 3 – specimen, 4 – clamping head, 5 – load, 6 – adjusting, 7 – power switch

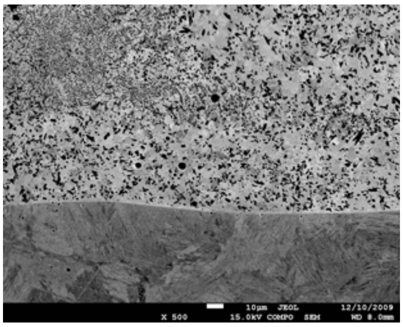

Fig. 2 Secondary electron micrograph of the microstructure of NP 60 coating, specimen 3,5/5

RESULTS AND DISCUSSION

Visual inspection of all coating types revealed a good continuous appearance of passes applied, without signs of surface cracks or lack of adhesion. SEM micrographs showing the typical microstructure of a section longitudinal to the laser scanning direction is presented in Fig. 2.

The microstructure of the melted layers consists of a solid solution of Cr and Fe in Ni matrix, forming a dendritic structure with an interdendritic lamellar eutectic phase made up mainly of Ni and Ni, Si and Cr-rich precipitates.

The absence of porosity and microcracks indicates that the processing parameters selected in this study have ensured a high quality of laser-clad coatings. It can be observed that the clad zone has a non-homogeneous microstructure, most probably because of local changes in solidification conditions (Fig. 2).

The semi-quantitative analyses carried out in the different zones using EDX show that the composition of the matrix is practically constant through the entire track. The thickness of clad layers was in the range of 0.7 – 1.2 mm. Fig. 3 gathers values of particular element concentration as a function of distance from the interface to the outermost zone as well as into the substrate. As can be seen in Fig. 3 iron content in the coating is less than 20 % and remains almost constant in the whole thickness. The same value of dilution was observed in specimens produced by higher laser beam power settings, (Fig. 5). Specimens prepared by the lowest speeds (specimen numbers 3,5/3 and 4,3/5) show higher Fe dilution for both laser beam power settings.

The dilution of Fe by these parameters is up to 40% as shown in Fig. 4 and 6. The low dilution generally ensures a perfect bond between the metal and the clad layer, and on the other hand the low level of dilution confirms the quality of the coating compared with the initial composition. 40% Fe dilution is quite high. Lower cladding speed in specimens 3,5/3 and 4,3/5 implied a higher amount of heat that was introduced into the process. Higher heat melts the substrate more intensively, which results in a higher mixture of melted powder with a substrate rich in iron (Fe). The concentration of iron in the solidified coating is then higher. The silicon content in the clad zone is around 4%, the chromium content around 16% and the nickel content between 60 - 75%. In specimens with higher Fe dilution, the Ni content was between 50 - 60%. All of these values indicate that the final composition is sensitive to the cladding parameters of the laser beam. The final composition of clad zones produced by higher cladding speeds was similar to that of the initial alloy. The small differences found between initial and final compositions are due to impossibility of quantifying boron and carbon with the analysis technique used.

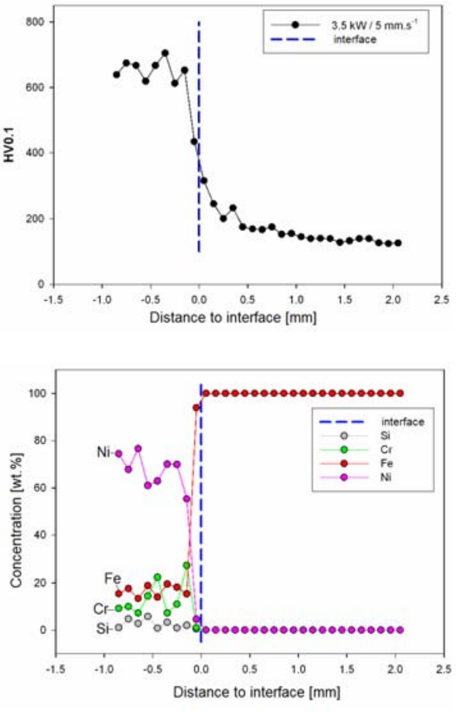

Fig. 3 Hardness profile and EDX analysis of specimen 3,5/5

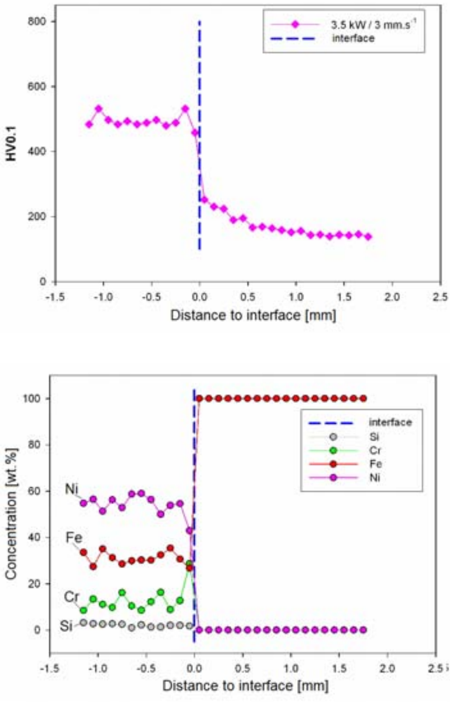

Fig. 4 Hardness profile and EDX analysis of specimen 3,5/3

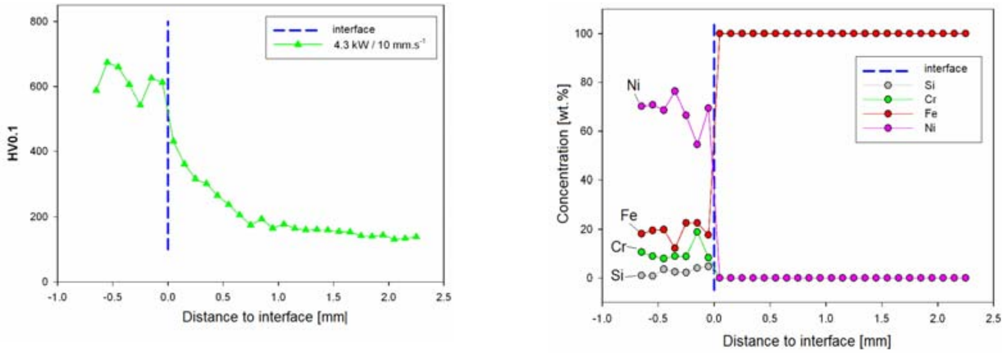

Fig. 5 Hardness profile and EDX analysis of specimen 4,3/10.

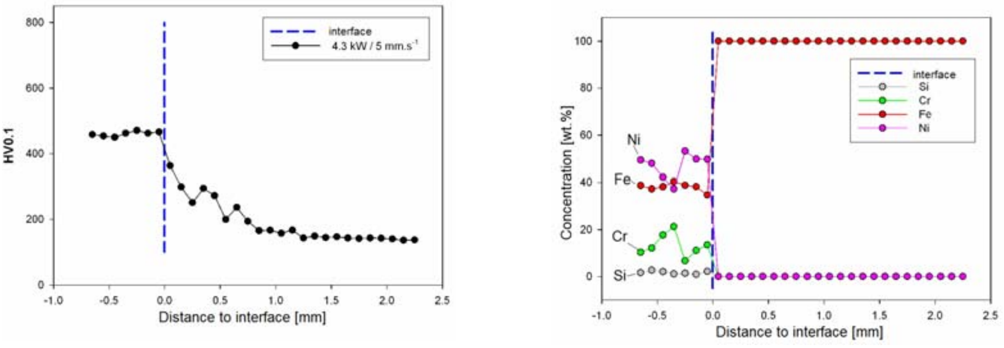

Fig. 6 Hardness profile and EDX analysis of specimen 4,3/5.

Microhardness profiles of coatings prepared by 3.5 and 4.3 kW laser power are compared in Fig. 7 and 8. At laser power setting of 3.5 kW (Fig. 7), the highest hardness values between 620 and 700 HV0.1 were reached by the specimens produced with a cladding speed of 5 and 7 mm/s (specimen 3,5/5 and 3,5/7). The lowest hardness was measured on the specimens clad at a speed of 3 and 10 mm/s (specimens 3,5/3 and 3,5/10). The differences in hardness values were measured also in the heat affected zone. A very similar character of hardness was observed in the profiles of specimens produced with a laser beam power setting of 4.3 kW, displayed in Fig. 8. The highest hardness was attained by specimens clad at a speed of 7 and 10 mm/s (specimens 4,3/7 and 4,3/10). The hardness values measured fell within a narrow range of between 580 and 620 HV0.1 However, these are slightly lower (40 - 80 HV0.1) than those presented in Fig.7. The lowest hardness was seen in the specimen with a cladding speed of 5 mm/s. It can be stated that with increasing speed of cladding, the hardness of NP 60 coatings increases at both laser beam power settings. The highest hardness values were reached at 3.5 kW. The lowest hardness values correspond to the highest values of iron dilution in coatings. It can be assumed that higher concentration of iron in the clad zone results in a decrease of hardness in the specimens with the highest heat input.

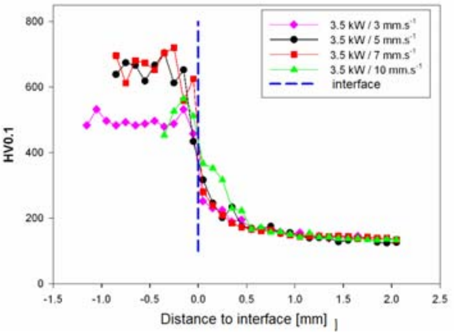

Fig. 7 Hardness profiles of laser clad coatings manufactured by beam power 3,5 kW.

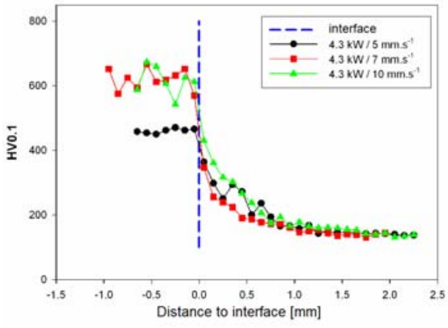

Fig. 8 Hardness profiles of laser clad coatings manufactured by beam power 4,3 kW.

Fig. 9 shows the comparison of weight loss after abrasion of the reference steel substrate and specimens with laser clad coatings prepared by different manufacturing parameters. It can be seen that the difference between steel and NiCrBSi coatings is significant. The weight loss of the substrate was about two times higher than that of coatings.

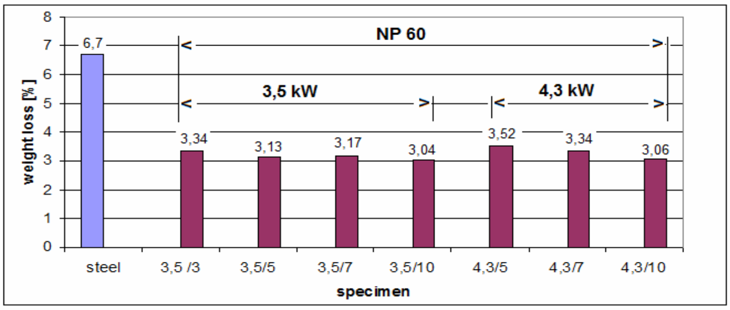

Fig. 9 Weight loss of specimens after abrasive wear.

The lowest values of weight losses were obtained for specimens clad at a speed of 10 mm/s for both laser beam power settings. The highest weight losses were observed in specimens with the lowest hardness, particularly 4,3/5 and 3,5/3. So, the best wear resistance was exhibited by coatings manufactured with the highest cladding speed. Generally, it can be stated that the wear resistance of claddings subjected to abrasion on the 146 m track increases with the increasing speed of cladding at both laser beam power settings (3.5 and 4.3 kW).

In an attempt to identify the wear mechanisms taking place in the different laser claddings, the worn surfaces were examined by SEM. The mechanism of wear abrasion was very similar for all types of coatings. A typical worn surface can be seen in Fig. 10. It reveals deep parallel scratches in the sliding direction, with plastically deformed edges, caused by the hard abrasive SiC particles in the coating after the test. Examination of the worn surfaces indicate that the grooves are steep-side and correspond well in size to the abrasive particles, showing that, in this case, cutting and ploughing were the main abrasive wear mechanisms.

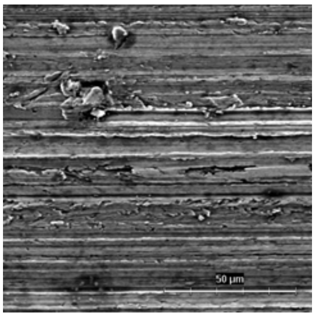

Fig. 10 SEM image of worn surface of NiCrBSi coating, generated by the microscale abrasion (specimen 3,5/3).

CONCLUSIONS

In this work, the influence of laser cladding parameters on the microstructure and abrasive wear behavior of NiCrBSi coatings is analysed. On the basis of experimental results obtained from the two power settings of laser beam and the various cladding speeds the following can be stated: If the right parameters are selected, laser cladding can provide good quality coatings with a hardness of around 700 HV0.1, good adherence to the substrate, and a virtual absence of pores.

Lower speeds of cladding imply higher heat introduced into the process. Higher heat melts the substrate more intensively which results in a higher content of melted substrate metal (Fe) in the solidified coating. Higher dilution of iron results in a decrease in the hardness of the cladded coating in specimens with lowest cladding speeds.

The difference in wear behavior between steel specimens from substrate material and specimens with laser clad coatings is significant. The weight loss after abrasion in steel specimens was two times higher. Only slight differences in weight loss between coated specimens were observed. Results obtained indicate that wear resistance of cladded coatings is higher in specimens with a higher hardness. In this order the lowest wear resistance was found in specimens with the lowest cladding speeds (specimens 3,5/3 and 4,3/5).

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