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CHARACTERIZATION OF THICK HARD LAYERS WITH Ni-Cr-B-Fe-Al ALLOY OBTAINED BY LASER CLADDING

Elena DRUGESCU, Simona BOICIUC, Constantin GHEORGHIES
"Dunărea de Jos" University of Galati, Romania
email: simonaboiciuc@yahoo.com

ABSTRACT

To increase the resistance to wear and corrosion of the surface layers made from steel with 0.45% C, multilayer deposition was tested by injection of powder with chemical composition of 8.9% Cr, 4.5% Fe, 5.1% B, 2, 4% Al, 0.6% Al; the remaining Ni, was melted in the bath with a CO_2 laser in continuous wave and coupled to a mass in coordinates x-y-z. To establish the optimum deposition condition, the layers made with different laser regimes were characterized by macro-and microstructural analysis, qualitative analysis of phase with the radiation difractometry X microhardness analysis and determination of hardness on the surface of the deposited layer. Thermal stability of the laser deposited layers and their abrasive wear behavior were monitored.

KEYWORDS*:* laser cladding, nickel alloy, microstructure, microhardness, difractometry, thermal stability

1. Introduction

Laser cladding is predominantly used to obtain highly resistant layers to wear and corrosion. Laser cladding was defined as a process used to melt, with a laser beam on a substrate, a material having different physical and mechanical properties. In order to maintain the original properties of the material deposited, only a very thin layer of the substrate must be melted to obtain the minimum dilution (0.5 - 3%) of the metallurgical bond of the additional material with the substrate. Both structure and properties depend on the melting temperatures of the support and the material deposited, the chemical composition and they may vary by applying various thermal regimes and granulation of the powder added [1, 2].

Laser cladding may be achieved in one step, when the addition material (powder, wire) is fed right in the laser-material interacting area or in two steps, when the addition material pre-cladding takes initially place (by electric-cladding, coating, thermal spraying or in plasma, paste, etc.) and further by laser processing [1, 2, 4].

The one-step process has several advantages against the two step process:

- Larger areas which need several adjacent layers application may be treated by smaller dilution;
- Cladding layer thickness may vary straight by controlling the feeding speed;
- Complex geometry items may be manufactured as material is continuously fed in the working area;
- The running cycle is simpler and easier to be performed;
- The cladding quality is higher, without porosity and with low roughness;

This paper presents the results of multilayer deposition by laser injection into melted bath of the powder alloy with the nickel base in the Ni-Cr-B-Fe-Al system. The optimal deposition regime, the thermal stability of the laser cladding layers and their behavior to abrasive wear were studied.

2. Experimental conditions

„Alliages Speciaux 7569 Alliajes Frittes, France" powder with the following chemical composition 8,9%Cr; 4,5%Fe; 5,1%B; 2,4%Al; 0,6%cCu; rest Ni [5, 6] was used for cladding. Grain fractions from 80-90 μm range were screened separately in order to be used as addition material. Powder had a spherical shape, which provided a fluid flow of addition material through the injection system. Before the addition of material feeding into the system tank, power was dried at 110°C temperature for 15 minutes [6].

Cladding was performed on a 1C45, SR EN 10083-1:1994 steel sample in refined condition.

Lab experiments were performed by a Laser GT 1400W (Romania) type CO_2 continuous wave installation with x-y-z coordinate running table and computer programmed running, provided by powder injection system on the laser melted surface, which exists at S.C. UZINSIDER ENGINEERING Galati.

After adjusting the power level of laser radiation and laser beam diameter on the sample surface, depositions were carried out under the form of parallel strips partly overlapping, with a transverse advance step of 1.5 mm. Final layer thickness was the result of overlapping 4-5 layers.

To determine the optimum laser cladding the flow rate of material added, the surface scanning speed and the initial sample temperature were varied. Table 1 shows the working conditions and the thickness of the layers deposited for some experimented working regimes.

The layers so obtained were macro and micro-structurally analyzed with $HV_{0.98}$ (load 0.98N) micro-hardness profile tracing in cross section of laser stripes, making also a phase quality analysis by X ray difractometry at the cladded layer surface, by DRON 3 Difractometer using a copper anticathode, mono-chromatic diffracted beam, U=34kV, I=30mA; F1=2mm; F2=0,5mm; ω=1°/min; v_{strip}=720mm/h, at diffraction angle variation between the limits 2θ = 20°.... 75°. HV_5 hardness measurements were performed on the cladded layer. Also the regime considered optimum was used to achieve deposition to study the thermal stability of the laser cladding layers and their behaviour to the abrasive wear.

Table 1. *Working regimes used in laser cladding*

Sample code	Added material rate	No. of overlapping runs	Working regimes					
			P	v	d_s	p_{av}	g	Hardness HV_5
	[mg/s]		[W]	[mm/s]	[mm]			[MPa]
1	55.5	5	1150	9	1.8	1.5	1.5	10490
2	105	4	1150	7.5	1.8	1.5	2.07	11450
3	105	4	1150	11	1.8	1.5	0.59	9593

NOTE: P - laser radiation power, v – scanning speed of the laser beam of the processed surface, d_s – diameter of the laser beam on the surface under processing; p_{av} - transverse advance step, g - thickness of layers deposited; m_p - flow rate of material added

3. Experimental results and discussions

The macroscopic analysis underlined the quality of the deposited surface, compactness, deposited layer thickness and its adherence to the base. There are noted thick layers with good adhesion to substrate, compact and smooth surface of the deposited layer (Fig. 1), so that further mechanical processing is minimal. Regarding the influence of the working regime on the surface quality, compactness and thickness of the deposited layer good results were obtained in a much broader spectrum of working regimes. It is found no influence of the base on the chemical composition throughout the depth of the layer deposited after five loading passages.

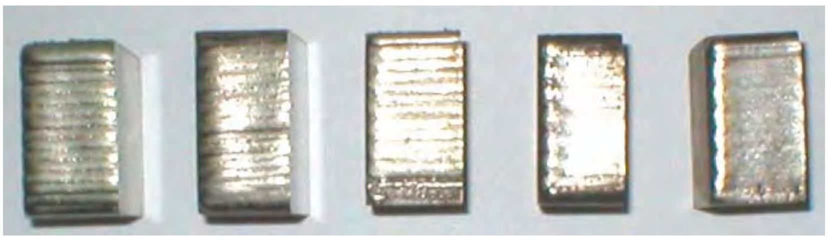
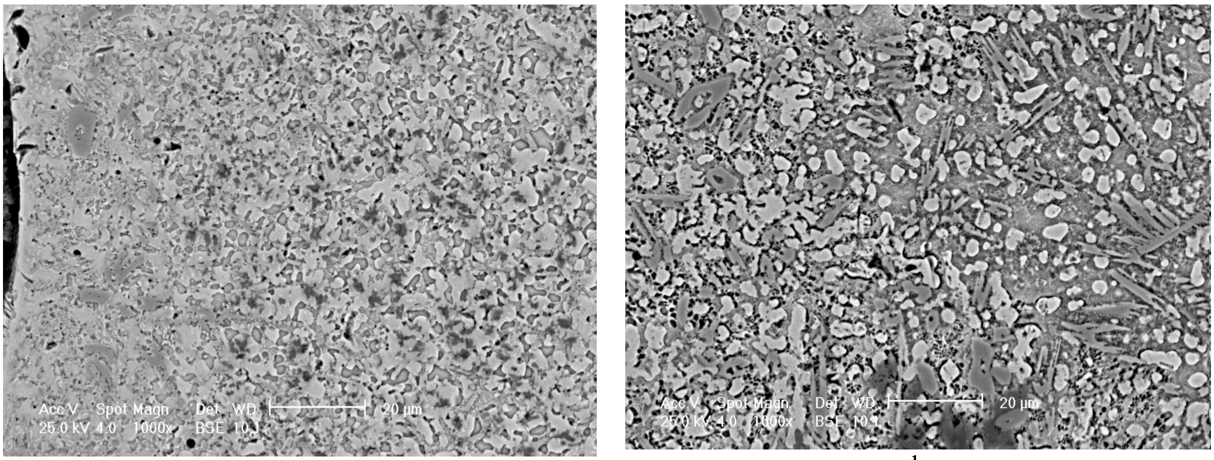


Fig. 1. *Samples covered with thick layers of nickel based alloy*

To highlight microstructural aspects of the layers deposited metallographic analysis 1000x were carried out, the metallographic attack being achieved by electrolyte. Figure 2 shows the microstructure of the layer deposited on the sample code 2.



a. b.

Fig. 2*. Microstructure of nickel – based alloy deposited on the sample 2 (v = 7.5 mm /s, m_p = 105 mg /s) a) base of layer deposited; b) layer surface(x1000). Electrolyte attack, solution 50% HNO_3.*

According to phase qualitative analysis (Fig. 3), deposit microstructure includes solid solution based on nickel, eutectic colonies and fine precipitates of boride like NiB, Ni_2B, CrB, Cr_3B_4 and FeB, main hardening phase being CrB. At the layer base there is a narrow zone of nickel-iron dilution without eutectic carbides, which makes the transition to the material support and provides a good adhesion of the layer to the support. In the presence of aluminum, the nickel can form inter-metallic compounds with hardening effect: Ni_3Al,Ni_2Al_3.

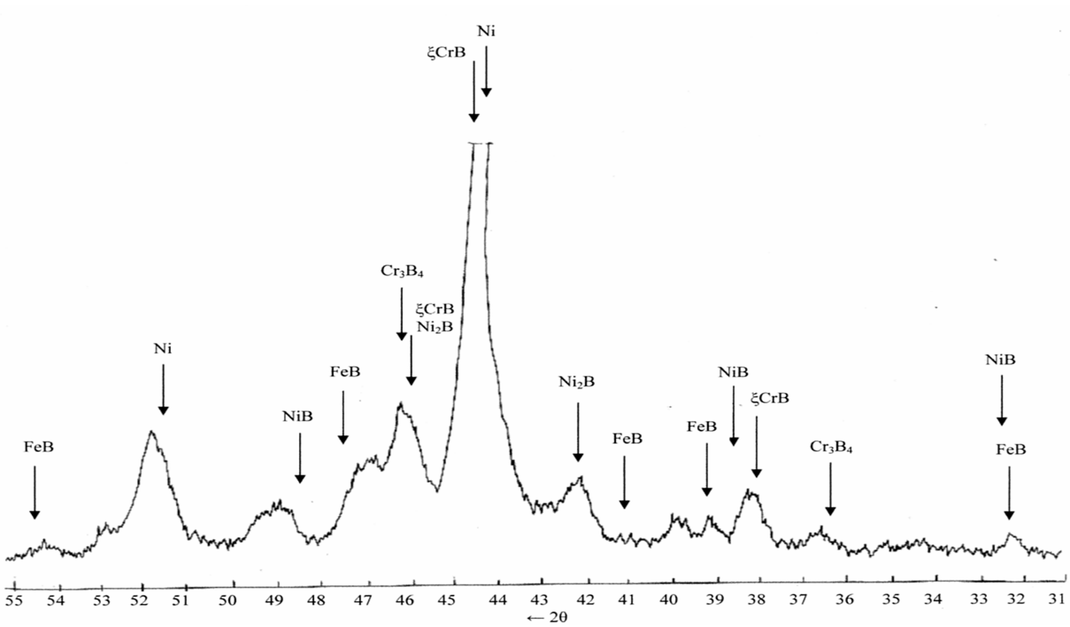


Fig.3. *Diffractogram for the layer cladded on the nickel base alloy test 2.*

Figure 4 shows the variation of micro hardness HV0, 1 on the depth of the layer deposited by the laser on samples code 1, 2 and 3. Max hardness and thickness of the layer are found in sample 2, at which scanning speed was minimal and the flow rate of injection material was maximal. Since the laser beam provides the main energy for melting the added material added, the scanning speed should be correlated with the flow rate of the material added.

The more the material addition, the lower the scanning speed, which provides a maximum thickness of deposited layer.

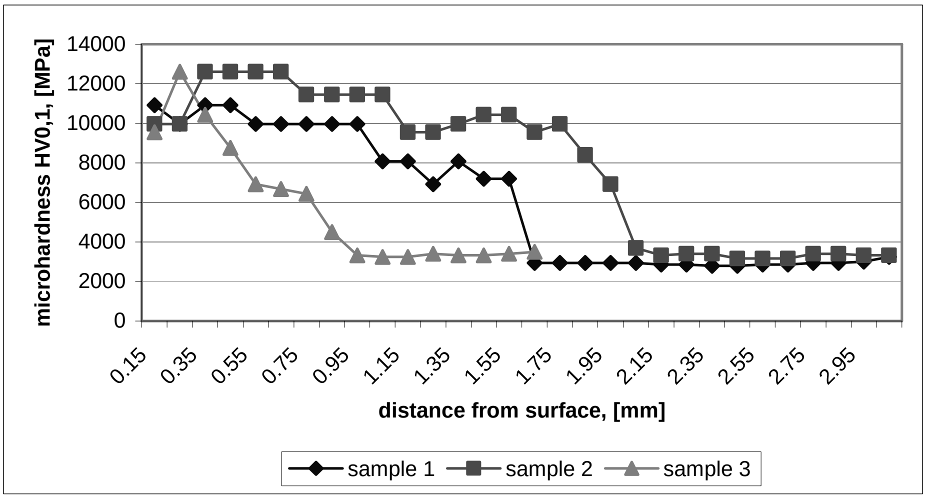


Fig. 4. *Variation of Vickers microhardness with the distance on the surface of the layer cladded on samples 1, 2, 3.*

From above, it is found that the optimal deposition regime is that of code 2, which provides the highest hardness and thickness. It was used to achieve the samples for determining thermal stability and behaviour to the abrasive wear of the layers deposited by laser with the nickel alloy tested. Since the literature [1, 2, 3, 4] recommends using nickel-based alloys for items subject to heavy wear and corrosion at high temperatures, the study of thermostability of the laser deposited layers was very convenient.

Thus, the samples deposited under regime 2 were heated to 700 °C (sample code 1), 800 °C (sample code 2), 900 °C (sample code 3), with exposure to each temperature for 1 hour, 2 hours and 3 hours respectively, after which the hardness was measured. Figure 5 shows the variation of micro hardness with the deposited layer depth, and figure 6 illustrates hardness variation on the deposition surface with the temperature. It is noted that as the heating temperature and exposure time increase, hardness and microhardness decrease due to dissolution of the precipitates in the nickel matrix.

The abrasive wear behavior of laser deposited layers with the nickel alloy base has been studied according to STAS 9639-81. The method uses a connection of peg / disk friction of class IV-1. The method consists in pressing sequentially, under identical conditions, two tubes of dimensions 6.2 x 6.2 mm, one from the material examined deposited by laser and the other from a material chosen for comparison purpose – improved carbon steel of 0.45 % C on a rotating disk covered with grinding paper of 120 grains. A mechanism for radial displacement of the tube with 0.5 mm / r provides a spiral movement on the surface of the rotating disk.

A device for implementing a load of 8.387 N ensured perpendicular pressing of the tube on the grinding paper at the pressure of 0.215 N/mm^2. At disk speed of 25 rpm, a number of 134 rotations have provided a length path of 84 m. The results obtained, as an average of three determinations, are presented in table 2. It can be noted that nickel based alloy is more resistant to abrasive wear than steel samples 1C45, with relative mass wear of 40%.

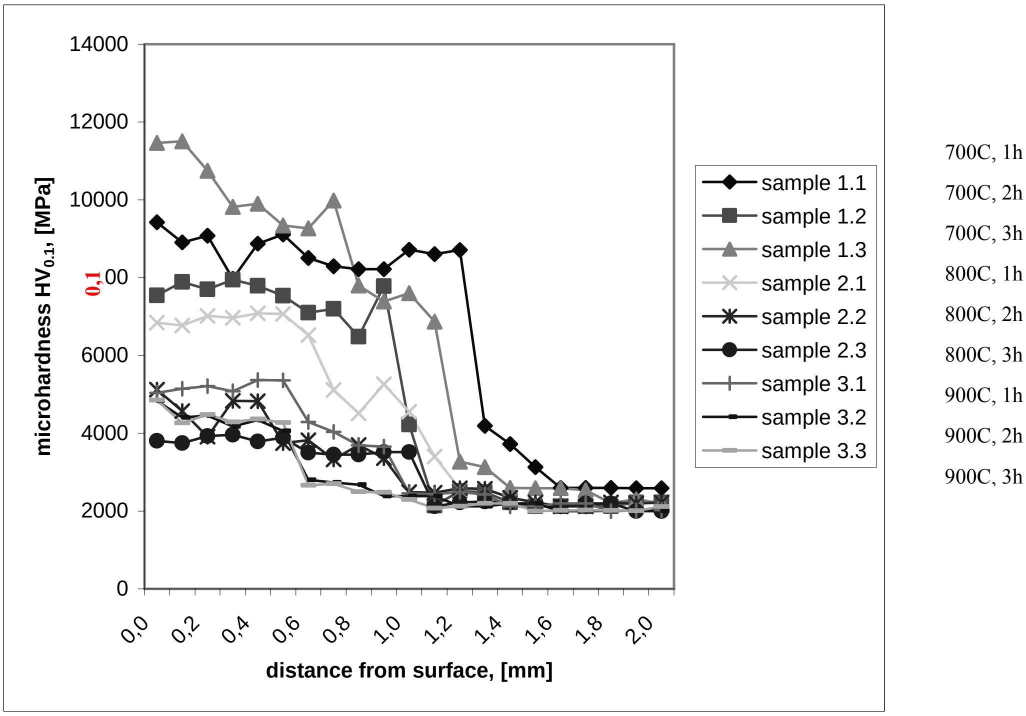


Fig.5 *The variation of Vickers microhardness with the distance on the surface of the layer cladded after heating at 700, 800, 900 ° C for 1, 2, 3 h.*

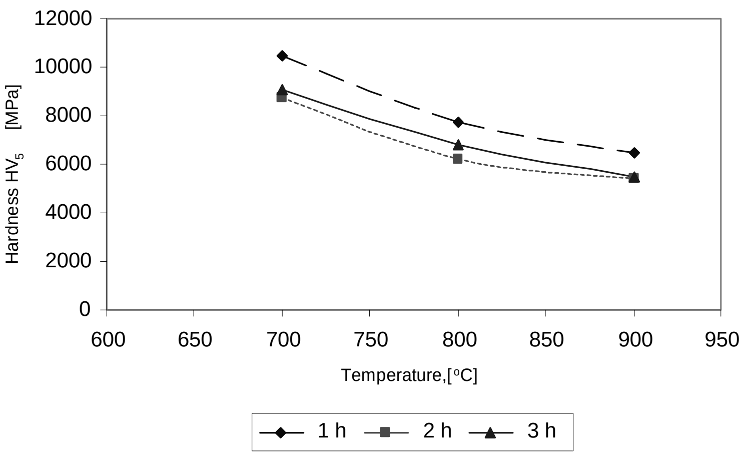


Fig. 6. *Variation of hardness HV5 of the layer deposition with the heating temperature for samples, code 1, 2, 3.*

Table 2*. Abrasive wear behavior of the nickel alloy deposition and the support*

Material	Initial mass	Final mass	Mass wear	Wear / way	Relative mass wear
	[g]	[g]		[g/m]	[%]
1C45	2.9150	2.7270	0.1880	0.0028	64
NiCrBFeAl	2.8805	2.7650	0.1155	0.0017	40

Figure 7 shows the mass wear variation with heating temperature for samples code 1, code 2, code 3. It can be seen that wear increases with the heating temperature, faster at 900 0C, due to the dissolution of precipitates in the nickel matrix, which leads to lower hardness of the deposition. Nickel- based alloy shows a good resistance to wear as compared with the support even at temperatures of 900°C at two hours' exposure times.

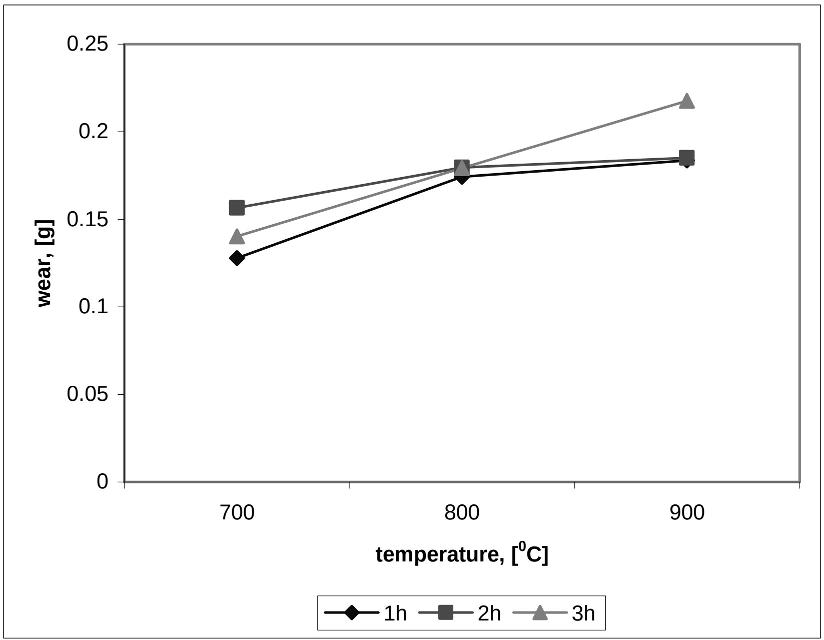


Fig. 7. *Variation of mass wear with heating temperature for samples code 1, code 2, code 3.*

4. Conclusions

By multi-layer deposition with beam laser in continuous wave it can be achieved thick compact layers of nickel alloy resistant to wear and corrosion, from the Ni-Cr-B-Fe-Al system with good adherence to the substrate by a low dilution layer. Deposition with laser of powder injected into the melted bath is a complex process of mass and heat transfer which is effective in a system of powder injection in continuous flow and constant flow rate. If deposition is carried out with a power laser beam and given sizes, hardness and thickness of layers depend on the flow rate of the material added, the surface scanning speed, initial temperature of the sample, the number of overlapped layers and the degree of overlapping laser bands. The degree of dilution is influenced by the powder flow rate and the energy factor used. The optimal deposition regime for the nickel alloy (sample 2) has provided a compact layer of thickness 2 mm, with micro hardness HV0, 10 of 11450MPa.

The testing to mass abrasive wear revealed that the resistence to abrasive wear of the laser deposition is higher in the carbon steel reference material by 0.45% C. Relative mass wear of the deposition was 40%.

As regards the behaviour of the laser deposited layers by heating at different temperatures it has been found that with increased heating temperature and exposure time, their hardness decreases. This may be correlated with the dilution of precipitates in nickel matrix and decrease in the hardness of the deposited layer. A minimum required hardness of 7000MPa is kept up to 800 ° C, after 3 hours heating.

The abrasive wear behaviour of laser deposited layers with the nickel alloy base has revealed the following: the increase in the heating temperature causes poorer wear resistance, more pregnant at 900 °C; for samples heated to 700 °C wear increases faster after 2 hours' exposure at those heated to 800°C, the wear can be considered stationary, while by heating to 900 °C, wear becomes more pronounced after three hours' exposure as a result of considerable decrease in hardness.

It follows that it is possible to use laser deposition of alloys Ni-Cr-B-Fe-Al under conditions of intense abrasive wear up to temperatures of 800 °C.

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