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STUDIES AND RESEARCH ON THE HARDENING OF SOME INDUSTRIAL BENCHMARKS THROUGH LASER CLADDING

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ABSTRACT

Industrial benchmarks are often subject to the wear and corrosion of the working environment. Laser cladding is a surface modification process that can improve their lifespan by ensuring hard, homogeneous, non-porous layers. The paper presents a series of experiments aimed at testing and calibrating the injection system used, making laser cladding with Ni-Cr-B-Fe-Al alloy on a series of industrial benchmarks and characterizing them in terms of hardness, thickness and microstructure.

KEYWORDS: laser cladding with injected powder, continuous wave laser, hardening

1. Introduction

Industrial applications require benchmarks with special surface properties such as high corrosion resistance, wear resistance and hardness. Alloys with these properties are usually very expensive and there is interest in reducing the cost of parts with these surface properties. This can be achieved by depositing, with the help of a laser beam, of a hard and corrosion-resistant layer on an inexpensive substrate [1].

Laser cladding can be accomplished through a one- or two-step process. In the one-step process, the powder is blown into the area of interaction between the laser beam and the part. In the two-step process, the powder is initially deposited on the part and then processed with the laser. Both techniques have the advantage of the possibility of depositing a wide range of alloys, either by choosing an alloy in powder form or by a mixture of powders with the required composition. Laser powder cladding offers the possibility of developing new combinations of materials in the future.

The injection of the filler material in the form of powder, in the molten metal pool, generated with the laser beam, is a widely used method for modifying the chemical composition and the properties of the superficial layer of the benchmarks made of metallic materials. The method allows direct modification of the dimensions of the deposited layer (height and width).

A number of industrial applications of laser cladding aim to increase the wear resistance of bearings, pivots, axes, cutting tools and other parts that work in very severe conditions.

Duroc AB from Sweden has developed laser cladding technologies on valves for the nuclear industry and the wood industry [1].

To perform cladding on industrial benchmarks, the laser with active gaseous medium (CO_2+He+N_2) with electrical excitation is used. It presents a series of features such as: good focus, very high power and high-power density, moderate efficiency, safe operation and excellent beam quality [2].

An injection system is also required, which achieves the controlled supply of the powder. There are several types of powder feeders used in industry. Depending on the principle of operation, they can be classified into the following classes: gravity driven, mechanically driven (with wheels, extruder type - with worm screw for adjusting the speed of powder supply), in fluidized bed, vibrators. Their use depends on the size, shape, physical and mechanical properties of the powders. It was found that as the powder particle size decreases below 15μm, the fluidity of the powder decreases, which could affect the transport and supply of filler material during the cladding process. Thus, the use of injection systems that include pressure-assisted or vibrating feeders can ensure a continuous flow, with a uniform feed rate and a low feed rate of approx. 0.1 g/min. [2].

It was found that the use of spherical powders, obtained by gas atomization, ensures a better flow through the injection system. Also, the particles must have a fine surface and a narrow particle size distribution [3, 4].

There is also the possibility of combining the types of feeders mentioned in order to increase the stability of the feed flow rate with filler material and the variation of the powder feed speed [2].

In worm screw feeders, there is the possibility of their premature wear, due to the abrasive effect determined by the powder particles. This aspect can influence the quality and properties of the deposited layer and can increase maintenance costs [2].

The use of fluidized bed feeders eliminates these shortcomings, thus ensuring a continuous supply of filler material, which has the effect of obtaining layers with superior characteristics [2].

Feeders with a vibrating device ensure a feed rate of filler material between 8-2000 g/min. [2].

The injection systems must ensure as continuous a supply of filler material as possible (without pulsations and agglomerations), so as to achieve complete melting of the powder particles and to obtain a compact, homogeneous layer, uniform in thickness, without pores and cracks, with a good metallurgical bond with the substrate and with a low dilution [3, 4].

Thus, there is interest in the development of new powder feeding devices for laser cladding, the main concern being directed towards the direct control of the powder flow rate and feeding speed.

It is also important, for laser cladding with injected powder, and the configuration of the filler nozzle. Thus, nozzles for co-axial feeding of the powder and for lateral feeding can be found.

One of the advantages of the co-axial nozzle is its independence from the direction of movement.

In the case of lateral feeding, surfaces with complex configurations can be processed, and by adjusting the position of the nozzle, the angle of supply of filler material, which is usually between 38 – 45o and the distance between it and the part, the cladding efficiency can be increased.

The paper presents a series of experimental research on the laser cladding of a Ni-Cr-B-Fe-Al alloy (8.9 %Cr; 4.5 %Fe; 5.1 %B; 2.4 %Al; 0.6 %Cu; and the rest Ni) on the wear elements, from the manipulators, which have the role of centring the hot-rolled strip. The program of laboratory experiments included two stages: a. testing and calibration of the injection system of the filler material in the pool melted with the laser, for the identification of constructive improvements, which would ensure the expansion of the range of regulation of the powder flow rates; b. laser cladding of nickel-based alloy layers to ensure high wear and corrosion resistance and their characterization.

2. Experimental conditions

The injection system, used in the experiments, consists of a powder storage tank, a dispenser of the amount of powder used in the unit of time, an element for directing the powder jet and a nozzle to control the divergence of this jet. Under the action of the gravitational force and the gas flow, the powder passes from the tank into the dosing chamber with a worm screw. Here it is picked up by the worm screw and transported to the jet directing element. The powder is transported from the dispenser to the work area by means of a gas flow (argon). The feed speed depends on the speed of the worm screw and its dimensions. Afterwards, the powder is injected into the pool through the nozzle.

The powder injection system in the laser molten pool and its test and calibration stand are shown in Fig. 1 and Fig. 2 [3, 5, 6].

When creating the injection system (Fig. 1), materials with higher thermal conductivity and lower specific heat (copper and copper alloys) were used for the benchmarks exposed to laser radiation.

Also, to improve the transport conditions of the powder in the system until it is taken over by the carrier fluid, an additional source of kinetic energy was introduced by placing a vibrating device at 47 Hz at the top of the tank.

For the testing and calibration research, powder with spherical particles from a nickel-based alloy, with a grain size of 80 µm, was used.

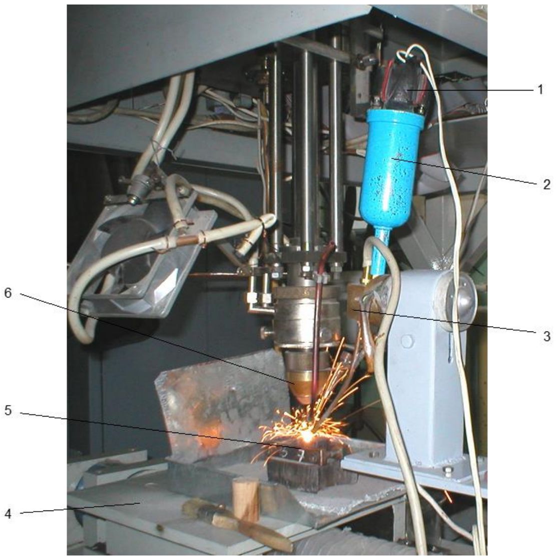


Fig. 1. *The powder injection system in the laser molten pool: 1 – vibrator; 2 – tank; 3 – dispenser; 4 – table in x-y coordinates; 5 – processed sample; 6 – laser head*

Fig. 2. *The test and calibration stand of the injection system: 1 – tank; 2 – dispenser; 3 – direct current electric motor; 4 – directing element; 5 – laboratory beakers; 6 – powder jet; 7 – voltammeter; 8 – autotransformer; 9 – rotameter; 10 – argon cylinder*

Before introducing the filler material into the tank of the injection system, the powder was dried at a temperature of 110 °C for 15 minutes. The moment of starting drying must be chosen so that, after extraction from the oven, the powder enters the processing process in a maximum of 30 minutes.

The laser claddings were carried out on the continuous wave CO_2 installation type Laser GT 1400 W (Romania), with transverse gas circulation, in cylindrical geometry, coupled to a work table in x-y-z coordinates ordered by a computer, provided by SC Uzinsider Engineering SA Galati, also provided with a powder injection system on the laser-melted surface.

The thickness of the layers deposited on the industrial benchmarks was determined at five points along each element, with the "SURFIX" SN 2731 device, and the three-point HRC hardness with the EQUOTIP durometer.

The metallographic analysis was carried out with a Philips scanning electron microscope, model XL 30ESEM TMP, resolution 3.5 nm equipped with an EDS spectrometer type EDAX Saphire.

3. Experimental results

a. Testing and calibration of the filler material injection system: In order to test and calibrate the powder injection system in the molten metal pool with the laser beam, a laboratory stand (Fig. 2) was made consisting of the powder injection system mounted on a stand, voltammeter, autotransformer, rotameter and cylinder with argon. With the help of the autotransformer (position 8) the value of the supply voltage of the direct current electric motor (position 3) is adjusted, which is measured with the voltammeter (position 7). The flow rate of the carrier fluid, provided by the argon cylinder (position 10), is finely adjusted with the help of the rotameter (position 9). Under the action of the worm driven by the electric motor and the pressure exerted by the argon, the powder is discharged through the nozzle in the form of a jet (position 6).

The change in the supply voltage of the electric motor determines the change in the speed of the worm screw and therefore in the powder flow rate. By changing the argon flow, the character of the powder flow through the nozzle is adjusted. Fig. 3 shows two images of the powder jet at different supply voltages and argon flow rates.

In order to test and calibrate the injection system, respectively to establish the correlation between the supply voltage of the electric motor and the powder flow rate at the exit of the nozzle, several laboratory beakers with known weight were used, in which the discharged powder was collected during the time interval of 1 minute, at different values of the supply voltage. The working parameters (from columns 1 and 2) are presented in Table 1.

Several attempts were made, and the results of the measurements (column 3) are presented in the same Table 1. The working times were timed, and the weighing was carried out with the analytical balance.

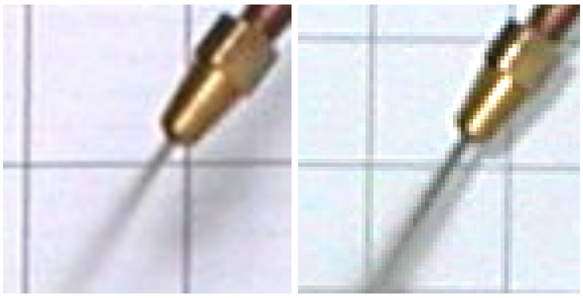


Fig. 3. *Aspects of the powder jet generated at different supply voltages and argon flow rates*

The literature [1, 7, 8] shows that under the conditions of using the laser beam, satisfactory deposits cannot be obtained with powder feeding speeds higher than 150 mg/s.

Comparing the values of the average flow ensured by the designed and realized injection system with the data from the literature, it results that the useful working regimes, when depositing the nickel-based powder, can be obtained by supplying the electric motor with direct current at voltages up to 15 V.

b. Laser cladding of the Ni-Cr-B-Fe-Al alloy on industrial benchmarks: For the hardening of industrial benchmarks, respectively the wear elements from the manipulators that have the role of centring the hot-rolled strip within the S.C. Liberty Steel. Galaţi, a Ni-Cr-B-Fe-Al nickel base alloy was used (8.9 %Cr; 4.5 %Fe; 5.1 %B; 2.4 %Al; 0.6 %Cu; and the rest Ni), with liquid phase hardening capacity specific to laser cladding [3, 9].

The hot-rolled strip, having a temperature of 550 °C, is centered on the winding mandrel with the help of manipulators whose wear plates touch the edge of the moving strip. This results in rapid wear through abrasion and oxidation of these plates. To increase their service life, it is necessary to deposit a superficial layer of material with superior resistance to wear and oxidation. As a result, on the guide plate, the wear elements processed by laser cladding will be mounted in the guides and fixed with bolts.

Table 1. *Working parameters for testing and calibrating the powder injection system*

No. item	**Tension (V)**	**Pressure (divisions)**	**Filler material flow**			
			Measured values (g)	**Average flow (g/min)**	**Average flow (mg/s)**	**% of maximum flow**
0	1	2	3	4	5	6
1	10	11	6.5840	6.5573	109.3	30.1
2			6.5571			
3			6.6258			
4			6.4622			
5	12.5	7	7.9740	7.8273	130.4	35.9
6			7.7871			
7			7.9458			
8			7.6022			
9	15	7	8.9040	8.9923	149.9	41.3
10			8.9471			
11			9.1058			
12			9.0122			
13	17.5	5	12.09399	12.32476	205.4	56.6
14			12.26713			
15			12.50579			
16			12.43216			
17	20	1	21.79399	21.77553	363.0	100
18			21.68713			
19			21.84579			
20			21.77583			

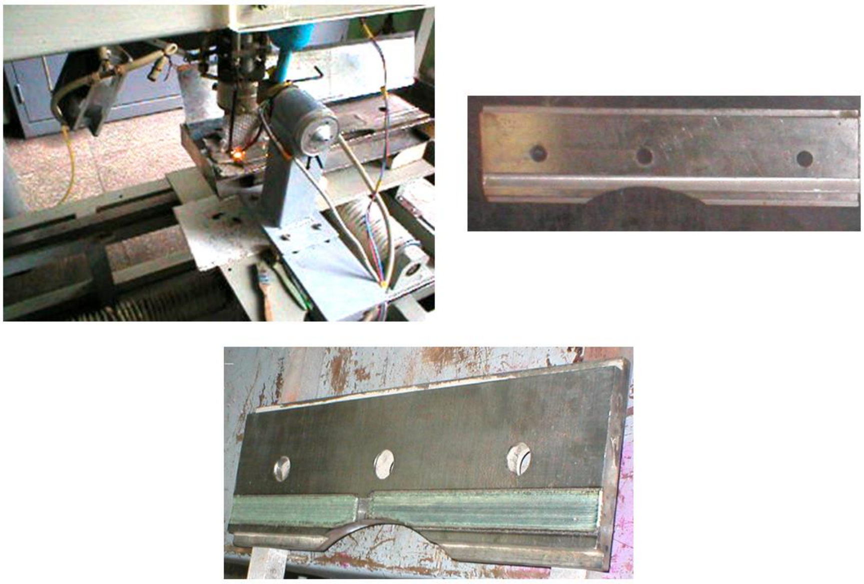


Fig. 4. *The cladding process and a wear element before and after the complete processing*

The wear elements and centring bolts were made of steel 1C45, SR EN 10083-1:1994 in improved condition, and the wear plates of steel S355JR, SR EN 10025+A1:1994.

In order to achieve laser cladding, the following were set: laser power 1150 W, active stroke length, number of active strokes (depending on the size of the surface on which the laser cladding is performed), transverse advance step 1.5 mm, active stroke speed 7.5 mm/s and transverse advance (10 mm/s), feed rates with filler material 105 mg/s.

The wear elements were processed by laser cladding of the hard nickel-based alloy, in the form of a thick layer of approx. 2 mm in the 2x20 mm longitudinal channel (specially provided for this purpose).

Fig. 4 shows the cladding process and a wear element before and after laser cladding of the nickel-based alloy.

Each wear element was subjected to cladding quality checks (adherence to the base material, layer thickness and hardness).

The adhesion of the deposited layers was checked with the help of penetrant liquids and the magnifying glass (x10). It was found that the deposits made are adherent, compact and have a good metallurgical bond with the substrate.

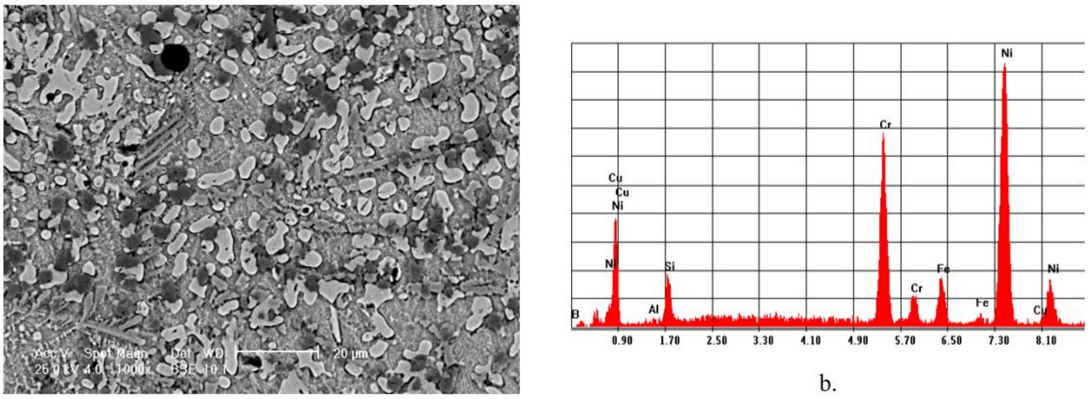
The thickness of the layer was determined at five points along each element, with the "SURFIX" SN 2731 device, and the three-point HRC hardness with the EQUOTIP durometer.

Table 2 presents the results of these determinations.

Fig. 5a shows the microstructure of the laser deposited layer with Ni-Cr-B-Fe-Al alloy and Fig. 5b the composition image obtained with the energy dispersive spectrometer.

Table 2. *Characteristics of Ni-Cr-B-Fe-Al alloy cladding*

No. item	**Wear element**	**Layer thickness (mm)**	**Adhesion**	**HRC Hardness**
1	Plate 1	2.1÷2.3	without detachments	68.58-66.88-67.73
2	Plate 2	2.2÷2.4	without detachments	69.58-67.72-68.65
3	Plate 3	2.1÷2.3	without detachments	68.89-67.22-68.06
4	Plate 4	2.1÷2.3	without detachments	68.00-67.44-67.72
5	Plate 5	2.1÷2.3	without detachments	69.03-66.44-67.73
6	Plate 6	2.2÷2.4	without detachments	69.05-67.92-67.00



a.

b.

Element	wt. %	At %
B K	0	0
AlK	0.52	1.02
SiK	6.07	11.52
CrK	21.33	21.85
FeK	6.56	6.26
NiK	63.86	57.95
CuK	1.66	1.39

Fig. 5. *a. SEM image of the microstructure of the deposited layer; b. composition image of the analysed area obtained with the energy dispersive spectrometer*

Analysing Fig. 5a. it can be seen that the microstructure of the achieved cladding is fine, with a dendritic columnar aspect, it also contains eutectic boron colonies (Ni_2B, NiB, CrB, Cr_3B_4, FeB) dispersed in a nickel-based solid solution. Fig. 5b highlights a high content of chromium and nickel and a minimum of iron and aluminium [3].

4. Conclusions

Laser cladding is a variant of technology that ensures a superior utilization of the processed material and the expansion of the fields of use.

The testing and calibration of the injection system highlighted the fact that by supplying the electric motor with a direct current, at different voltages, different feed rates of filler material can be obtained. By correlating them with the sweeping speed and laser power, deposits with superior properties can be obtained compared to the supports used. For a good, uniform flow of the powders in the tested injection system, it is recommended to use spherical, particle size homogeneous powders, usually obtained by gas atomization.

The deposits made on industrial benchmarks are characterized by compactness, uniformity (dimensional and compositional), adhesion, with a good metallurgical bond with the substrate.

The hardening effect, conferred by the fine and dispersed structure, which contains boron (Ni_2B, NiB, CrB, Cr_3B_4, FeB) ensures superior wear resistance and improved corrosion resistance.

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