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DETERMINATION OF FRICTION COEFFICIENT AT SLIDING INDENTATION OF LASER CLADDING WITH Ni – Cr – B – Fe – Al ALLOY

Simona BOICIUC, Constantin SPÂNU
„Dunarea de Jos" University of Galati
email: simonaboiciuc@yahoo.com

ABSTRACT

To increase resistance to wear of the surface layers made from 0.45% C steel, a multilayer deposit by powder injection with the chemical composition Cr 8.9%, 4.5% Fe, 5.1% B, 2, 4% Al, 0.6% Cu, and Ni was tested in a molten bath with a continuous wave of CO_2 laser, coupled to a table within x-y-z coordinates. The layers were characterized by microstructural analysis, qualitative analysis of phase with the radiation difractometry X and EDX microanalysis. It was determined the friction coefficient developed during sliding indentation in dry friction conditions.

KEYWORDS: laser cladding, powder injection, sliding indentation

1. Introduction

The sliding indentation test is today widely used, especial by the coating industry and coating development laboratories, as well as in research for evaluating the tribological properties of coatings and other hard surfaces. Different standards were elaborated in Europe and USA [1, 5].

In the sliding indentation test, an indenter (in this case a ball bearing) is pressed by a normal force on the workpiece surface, while being pushed by a force tangential to it.

Under static or quasi – static load application, maintaining the contact operating conditions requires limiting the plastic deformation in the contact area.

For the development of plastic deformation in a hertzian contact, the steps below are followed [1, 2, 3].

- ❖ smoothing the contacting roughness, with the total deformation less than 0.1 μ m;
- ❖ plastic deformation of surface roughness up to the formation of continuous contact surface with deformations of 0,1 to 10 μm;
- ❖ plastic volume deformation when exceeding the limit of elasticity, as a result of the material flowing beneath the contact surface, the plastic deformation exceeds 10 μm, and the material moves from the contact zone without dislodging the base material;
- ❖ seizing, which occurs at increasing deformation and implies adhesion, detachment and accumulation of material on the contact surfaces.

A material behaviour within an elasto-plastic range depends on: construction parameters (shape, dimensions) and operating parameters (kinematics, energy, environmental) of the contact; the surface layer parameters - microgeometry, metallurgical characteristics (chemical composition, purity, microstructure) and mechanical parameters (hardness, tension) [6].

It was found [1, 2, 3, 4, 6] that the value of the hertzian stress at which plastic deformation occurs in contact increases with the surface hardness. Also, the larger the frictional forces, the lower the plastic deformation where the seizing tendency occurs.

The choice of surface hardening processes, suitable to a certain material, is an important way to increase the bearing capacity of the contacting surface and reduce the tendency of seizing. Thus laser cladding with alloy Ni - Cr - B - Fe - Al constitutes an effective way to increase the surface hardness that directly affects their behavior to plastic deformation.

The characterization of the surface layers can be highlighted by an installation with a point contact sphere-plane which provides a sliding indentation in dry friction conditions. The evolution of the plastic deformation of the material tested when applying various normal forces led to the determination of the friction coefficients as an indicator of the seizing tendency.

According to the literature [1, 2, 3, 4, 6], the surface hardened materials transition from elastic to plastic deformation is continuous, so that the strain at the beginning of the plastic deformation (δ_p = 0.1 to

10 μm) can be expressed with an acceptable approximation by Hertz's equations.

For the point contact sphere-plane, the features are:

- Hertzian pressure:

$$P_{\max} = \left(\frac{6F \cdot E^{*2}}{\pi^3 \cdot R^2} \right)^{1/3} \quad (1)$$

where: F – normal force, E* - reduced elasticity module, R – indentor radius, P_{max} max pressure at Hertzian contact.

$$\frac{1}{E^*} = \frac{1-\nu_1{}^2}{E_1} + \frac{1-\nu_2{}^2}{E_2} \quad (2)$$

where: ν_1 , ν_2 - Poisson coefficients, E_1, E_2 elasticity modules of the indenter and surface being tested.

There is a linear relation between the material yielding point and hardness [7, 8, 9].

Thus: for non hardened material,

$$\mathrm{HV} = (2{,}9 - 3) \cdot \sigma_C \quad (3)$$

and for isotropic hardened materials, acc.to [10],

$$\mathrm{HV} = 2{,}475 \cdot \sigma_C \quad (4)$$

The calculation of the friction coefficient developed during the testing was carried out using the formula:

$$\mu_{med} = \frac{F_{fmed}}{F_{nmed}} \quad (5),$$

where: F_{fmed} : the average friction force;

F_{nmed} : the average normal force the friction forces being recorded by means of a force transducer.

This paper presents a study of the elasto – plastic behavior of some laser cladded samples with alloys of Ni - Cr - B - Fe - Al (code A and B) and the base material (code Mb) made from steel improved 1C45, SR EN 10083-1 : 2007.

The samples obtained were examined by metallographical, qualitative analysis of phase with the radiation difractometry X and EDX microanalysis. There were determined the friction coefficients developed.

2. Experimental conditions

For cladding purpose it was used the powder „Alliages Speciaux 7569 Alliajes Frittes, France” with the chemical composition: 8,9%Cr; 4,5%Fe; 5,1%B; 2,4%Al; 0,6%Cu; and Ni.

Cladding was made on samples from improved steel 1C45, SR EN 10083-1:2007.

It was used a continuous wave CO2 system, type Laser GT 1400W (Romania), with working table within x-y-z coordinate system and computer programmed working regime, provided with a powder injection laser on the melted surface.

The working regime used to form laser cladding with nickel-based alloy is presented in Table 1.

The sliding indentation rig is illustrated in Figure 1.

Table 1. *Working regime used in laser cladding*

Added material rate [mg/s]	No. of overlapping runs	Working regime					
		P	**v**	**d_s**	**p_{av}**	**g**	**Hardness HV_5**
		[W]	[mm/s]	[mm]			[MPa]
105	4	1150	7.5	1.8	1.5	2.07	11450

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

The mechanical composition of the kinematic chain and the presence of the frequency converter cause the feed speed of the horizontal column 9 to take very low values, being adjustable within the range from 0 to 0.172 mm/s. Under these speed conditions the sample strain can be considered quasi-static [9].

The measuring system consists of two identical force transducers (Fig. 1), which determine the normal force and tangential force, and a data acquisition and processing system. The force transducers are resistive full bridge type HOTTINGER BALDWIN MESSTECHNIK GmbH, C9A with measurement range 0 ... 50 kN.

The sample 16 and indenter 22 (Fig. 1) materialize the tribo-model considered in the study of deformations [5].

The tribo-model will therefore contain a point contact between a ball and a plan. The indenter (ball – mobile tribo-element) is held firmly in a mount, solitary to the vertical column 11 (Fig. 1), the only possible movement being sliding onto the sample, at the speed of the horizontal column 9 [9].

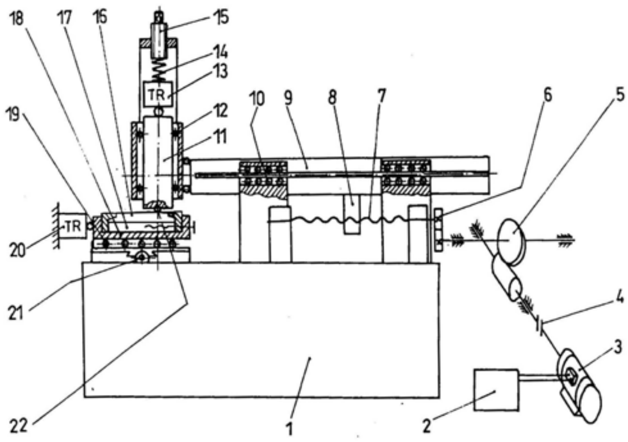


Fig. 1. *The components of the rig for sliding indentation tests*
1-frame, 2-ABB frequency converter, 3-electric engine, 4-elastic coupling, 5, 6, 7, 8-mechanical transmission, 9-horizontal column, 10-balls guiding, 11-vertical column, 12-balls guiding, 13-force transducer, 14-elastic system, 15-loading screw, 16- specimen, 17-sustenance surface, 18- specimen fixing device, 19-balls guiding, 20-force transducer, 21-screw for transversal movement, 22- indenter.

The fixed tribo-element consists of the samples to be analyzed (samples).

The samples have rectangular shape and the dimensions given in Table 2.

Table 2. *Characteristics of the fixed tribo-element*

Sample code	**Sample length**	**Sample width**	**Sample thickness**	**Hardness HV5**
	[mm]			[MPa]
MB	92	16	15	3400
A	92	24	15	9270
B	92	24	15	9385

Series of traces on each specimen were made, using a fixed ball mount. For this type of testing, the mobile tribo-element (ball) is subjected to two forces: one normal on the fixed tribo-element and one tangential to its surface. Initially the normal force is applied, the ball making a plastic deformation, and then the tangential one, resulting a trace under the form of an elongated groove.

The indenter speed is 0.15 mm/s, diameter ϕ 12.675 mm, is made from Rul 1 (SR EN ISO 683-17:2002), hardened and annealing steel. After each test, the ball bearing has been replaced with a new one that was degreased further.

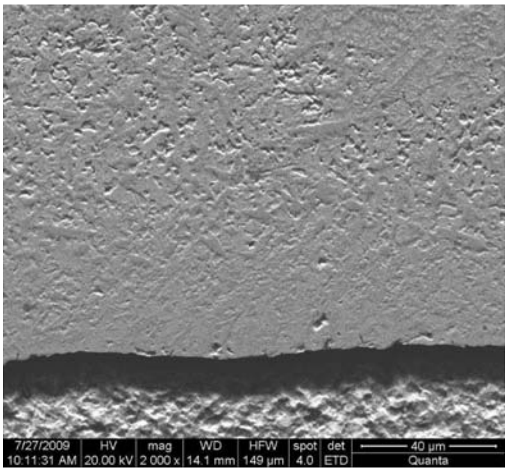
Before carrying out any test, the sample surfaces have been degreased with alcohol, to provide conditions for dry friction. The normal forces F_N. used for indentation were: F1 = 2.886 kN; F2 = 4.330 kN; F3 = 5.773 kN; F4 = 7.216 kN.

Roughness Ra, as measured by a roughness gauge Surtronic 3+, is Ra $\approx$0.210μm for all surfaces.

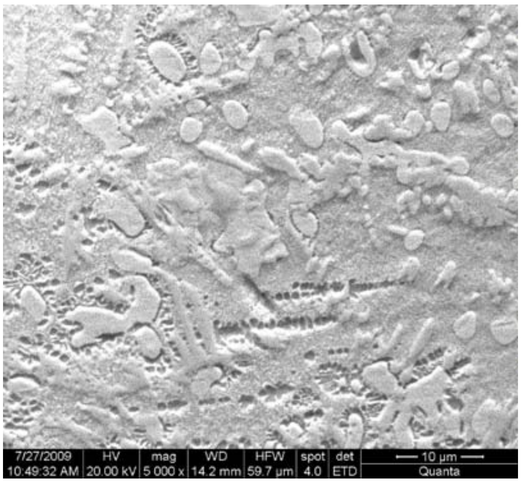
3. Experimental results and discussion

The microstructure of the nickel-based alloy laser cladded layer is presented in Figure 2, the attack being electrolytic.

According to phase qualitative analysis (Fig. 3) the columnar dendritic fine structure of the deposit contains nickel-based solid solution and eutectic colonies of borides (Ni_3B, CrB), CrB being the main hardening phase.



a.



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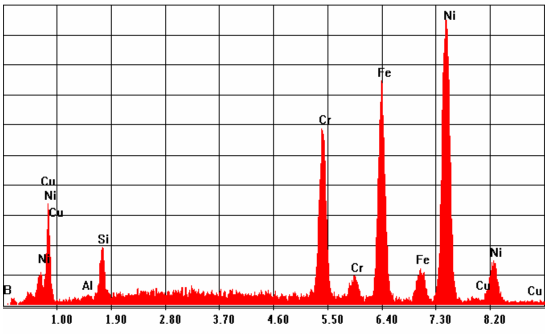

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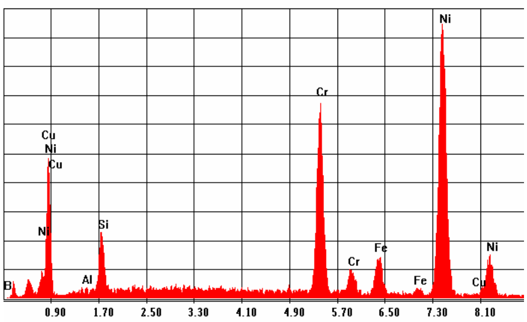

b.

Fig. 2. *Microstructure of nickel – based alloy and EDX results: a) base of layer deposited; b) layer surface(x1000). Electrolyte attack, solution 50% HNO$_3$*

Table 3. *The EDX results*

EDX results for base of layer deposited			EDX results for layer surface		
Element	**Wt %**	**At %**	**Element**	**Wt %**	**At %**
B K	0	0	B K	0	0
AlK	0.62	1.24	AlK	0.72	1.4
SiK	4.67	8.97	SiK	7.33	13.71
CrK	14.47	15.01	CrK	21.24	21.46
FeK	23.69	22.89	FeK	5.45	5.13
NiK	55.18	50.72	NiK	63.97	57.24
CuK	1.36	1.16	CuK	1.28	1.06

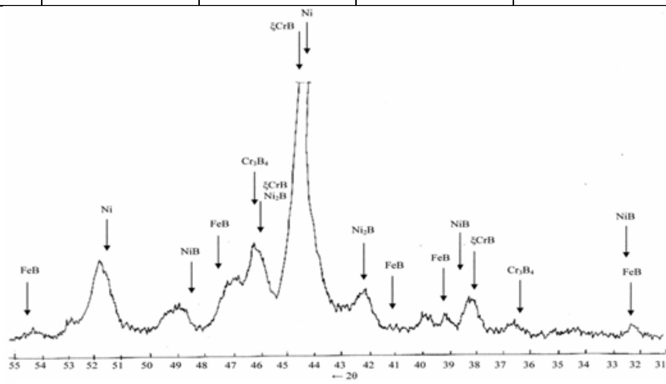

Fig. 3. *Diffractogram for the layer cladded on the nickel base alloy.*

At the bottom of the layer there is a narrow area of nickel-iron dilution without eutectic carbides, which makes the transition to the material support. Good adhesion of the deposited layer to the substrate is visible. In the presence of aluminum, the nickel can form intermetallic compounds having a hardening effect: Ni_3Al, Ni_2Al_3 [11, 12]. Table 3 shows the EDX results. If we analyze the EDX results we fiund that: the iron concentration decreases, and the chromium, nickel, aluminium concentration increases from base to surface.

Traces obtained from sliding identation for the basic material are presented in Figure 4. Maximum pressures, obtained by relation (1), for the normal forces used are given in Table 4.

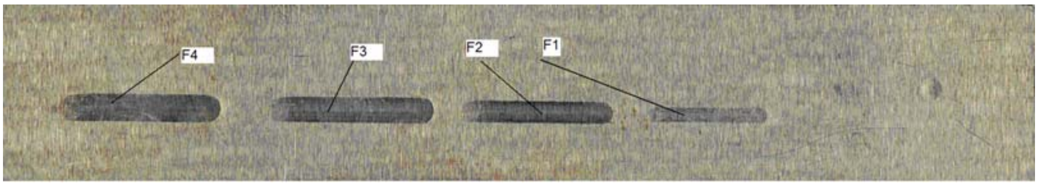

Fig. 4. *Picture of specimen MB with the sliding indentation tracks.*

Table 4. *Maximum pressure obtained for the normal strains applied*

Pmax [MPa]	**Normal force, F_N** [kN]
5773.529	2.886
6609.550	4.330
7274.611	5.773
7836.247	7.216

The variation of the friction coefficient with the normal force for the three samples is presented in Figure 5 and Table 5. The different values can be accounted for by the presence of intermetallic compounds (borides and carbides) which results in inhibition of adhesion.

Table 5. *Friction coefficient determined*

Sample code	**Normal force** [kN]	**Friction coefficient,** μ_{med}
MB	2.886	0.068
	4.330	0.079
	5.773	0.082
	7.216	0.093
A	2.886	0.079
	4.330	0.071
	5.773	0.049
	7.216	0.063
B	2.886	0.153
	4.330	0.055
	5.773	0.039
	7.216	0.040

Their amount increases from the base material containing cementite precipitates in sample A with a larger amount of borides in particular, reaching its maximum with sample B which has the highest hardness.

From Figure 5 we can see that for the base material (sample code MB) the friction coefficient takes the highest value, which increases with increasing normal force. This can mean a larger plastic deformation. As a result the friction surface is higher and so is the adhesion tendency.

Analyzing the behavior of sample A it can be seen an intermediate value of the friction coefficient (between those of samples MB and B). The explanation is on account of lower plastic deformation, due to a higher quantity of intermetallic compounds. This leads to reduced indentor penetration and less friction surface associated with a reduced adhesion tendency. This increase of friction coefficient occurs at a normal force greater than 5.65 kN.

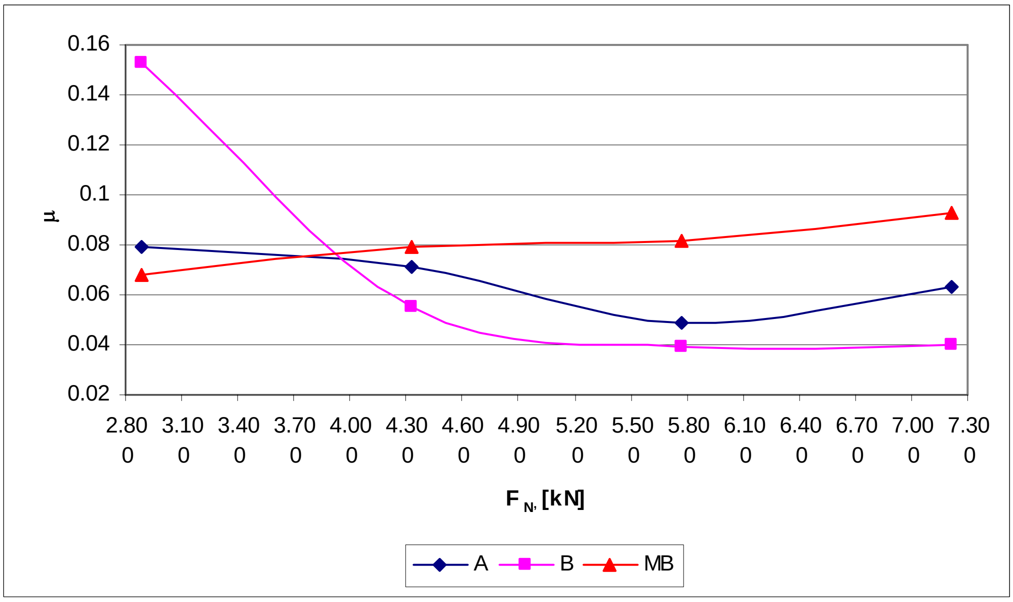

Fig. 5. Variation of the friction coefficient with the normal force for the three samples MB, A, B.

Analysing the behaviour of the sample code B, it is found that high hardness due to the large amount of borides makes plastic deformation be minimal.

The indenter penetration into material penetration is the lowest of the three cases, the low-friction surface associated with minimum adhesion has led to an extensive range of strains in which the friction coefficient is minimal.

Therefore in the range of forces concerned there is no tendency of adhesion and increasing friction coefficient.

Figure 6 presents track depth variation with normal force and Figure 7 presents track width variation with normal force.

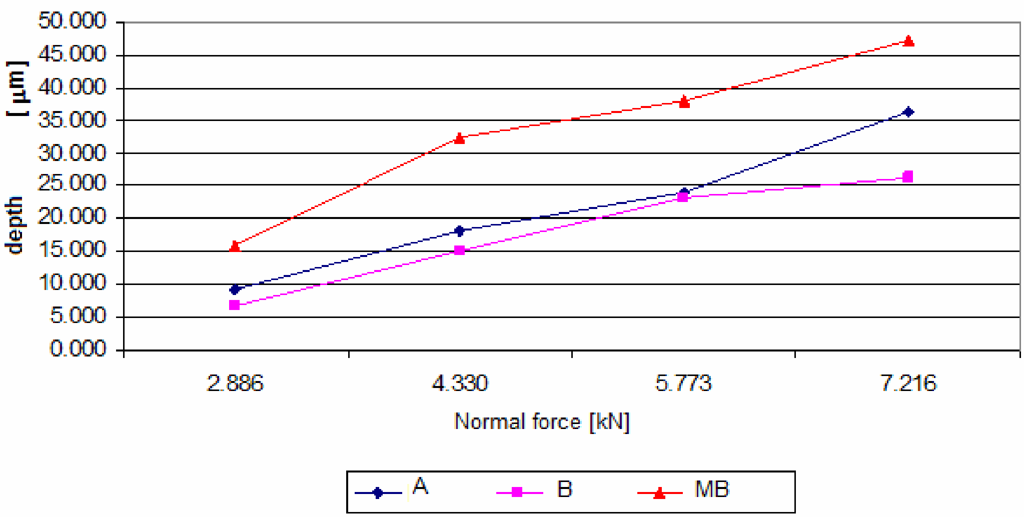

Fig. 6. Track depth variation versus normal force.

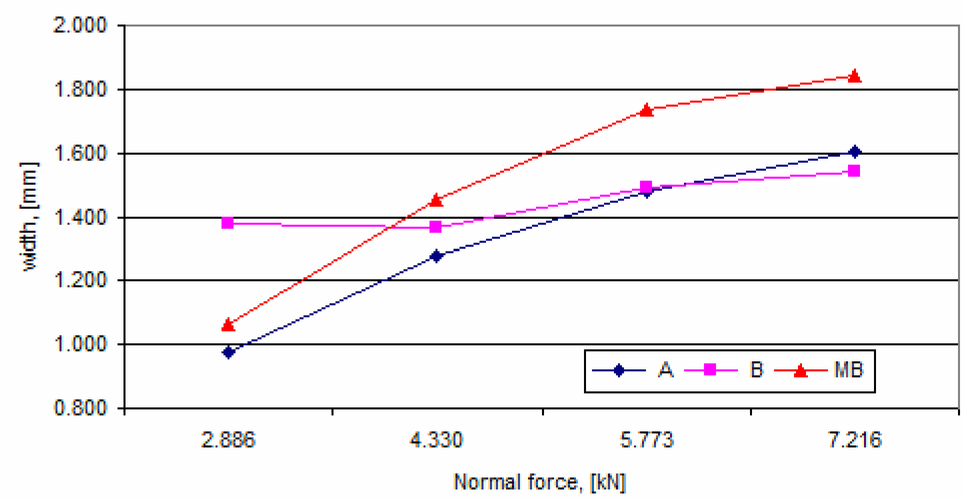

Fig. 7. *Track width variation versus normal force*

Form Figure 6, it could be noticed that for small normal forces the deformation depth of specimen code B is reduced but the zones near to the track begin to participate at the deformation process, recording a maximum width. With the increasing of the normal force, in depth deformation becomes prevalent and for the force F4 the width for specimen B get less than the width of the specimen A. Analysing the track width variation with the normal force (Fig. 7), it appears that trace depth growth occurs, due to normal force increasing and to the arising of plastic deformation, fact more visible for the substrat material.

4. Conclusions

The experimental research led to the following conclusions:

- laser cladding is an efficient way to move the elasto-plastic transition at higher contact pressures;
- with increased layer hardness and normal force, the friction coefficient decreases, and the material can be used at higher pressures;
- when increasing layer hardness, the trace depth is reduced;
- the comparisons of the geometrical characteristics of the different digital depth profiles confirm the better behaviour of the laser cladding layers.

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