IN MEMORIAM Prof. Dr. Ing. PETRU BALTĂ

REZISTENȚA LA UZURĂ A STRATURILOR COMPOZITE NiCrBSi OBȚINUTE PRIN PLACARE LASER

WEAR RESISTANCE OF LASER CLADDING NiCrBSi COMPOSITE COATINGS

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Laser cladding NiCrBSi composite coatings were deposited on the surface of stainless steel substrates using different scanning speeds. The influence of scanning speed on dilution rate and the coatings microstructure were investigated by Scanning Electron Microscopy (SEM), Energy Dispersive X-ray Spectroscopy (EDX) and X-ray diffraction. Analysis of microhardness, porosity and the wear behaviour of the obtained coatings were revealed. The coatings were analysed and finally compared to each other. It was found that the microstructure and wear resistance of the coatings were influenced by the scanning speed and dilution.

Straturile compozite pe bază de NiCrCSi au fost obținute prin placare laser pe suprafața probelor din oțel inox utilizând diferite viteze de scanare. Influența vitezei de scanare asupra raportului de diluție şi respectiv în ceea ce priveşte microstructura acoperirii au fost investigate cu ajutorul Microscopiei Electronice de Scanning (SEM), Spectroscopia EDX (EDX), cât şi cu ajutorul difracției de raze X. Au fost realizate analizele privind microduritatea, porozitatea şi rezistența la uzură a straturilor obținute. Acoperirile compozite studiate au fost analizate şi comparate. În urma testelor efectuate a fost evidențiat faptul că microstructura şi rezistența la uzură a acoperirilor studiate sunt influențate atât de viteza de scanare, cât şi de diluție.

Keywords: *laser cladding, coatings, wear resistance*

1. Introduction

Nowadays, in industrial applications laser cladding is one of the most important coatings manufacturing process and is applied for wear and corrosion protection of mechanical parts [1–3]. For hard phase coatings, laser cladding is performed as a one-step process. In this way a metallurgical bonding of the coating to the substrate is created, but dilution of substrate elements into the coating is kept as low as possible [4].

Laser cladding parameters including gas flow rate, powder, scanning speed, have a meaningful effect on the coating properties [5, 6]. In the literature many research works had been carried out in terms of scanning speeds, but not many focused on high power density, more than 20 kW/cm^2.

NiCrBSi alloys become very popular because of their good wear resistance and relatively low cost [7]. They are used to improve the quality of components such as pistons, rolling mills, tools, plungers, wearing plates, etc. whose surface is subjected to severe tribological conditions [8].

The present paper describes the results of research on the sliding wear behaviour of different NiCrBSi laser cladded coatings performed using five different scanning speeds at high power density. The cladded coatings were metalographically characterized to reveal dilution and cladding efficiencies and the wear behaviour was determined via pin on disk method. Finally the coatings were compared.

2. Experimental

2.1. Feedstock material

Commercially available NiCrBSi (Metco 12C) cladding material prepared by gas atomization with nominal size in the range of –125 ÷ +53 µm was used in all experimental series described below. The chemical composition of the powder, reported by the manufacturer, is presented in Table 1.

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Table 1

Chemical composition (wt.%) of Metco 12C feedstock powder
Compoziția chimică (% greutate) a pudrei Metco12C

Powder *Pudră*	Ni %	Cr %	B %	Si %	Fe %	C %
Metco 12 C NiCrBSi	Balance	10	2.5	2.5	2.5	0.15

Table 2

Laser cladding parameters / *Parametrii de acoperire laser*

	Laser power *Putere laser* [W]	Power density *Densitate de putere* [kW/cm^2]	Speed *Viteza* [cm/min]	Powder feed rate *Debit alimentare* [g/min]
Sample 1	780	24.8	16	5
Sample 2			20	
Sample 3			24	
Sample 4			30	
Sample 5			34	

2.2. Coating deposition

Laser cladding has been carried out using a Coherent 1000F diode laser and a Precitec YC50 water cooled cladding module manipulated by a CLOOS welding robot. The laser beam was used in infrared field with a wavelength of 975 nm and a maximum divergence of 56 mm·mrad. The powder was provided to the cladding head with AT-1200HPHV Termach feeding system and Argon gas was used for shielding and carrier of the powder.

The influence of different scanning speed on coatings properties was investigated. Five series of coatings were produced by varying the deposition speed from 16 to 34 cm/min, the other parameters being kept constant. The cladding parameters used in the present study are compiled in Table 2.

2.3. Characterization methods

The morphologies and microstructures of the powder and coating microstructure were studied by scanning electron microscopy (SEM) including EDX (Quanta FEG 250, equipped with EDAX analyzer – FEI). Vickers microhardness $HV_{0.3}$ was measured on the coating surface using a Zwick Roell microhardness tester at a load of 300 g force with 10 indentations per sample. An X-Ray difractometer with Cu Kα radiation was used to determine the phase composition. The XRD patterns of the powder and coatings were collected at 2θ angles between 20°–100° degrees. Image analysis software (ImageJ) was used to quantify the porosity and to determine the dilution in the laser cladded coatings.

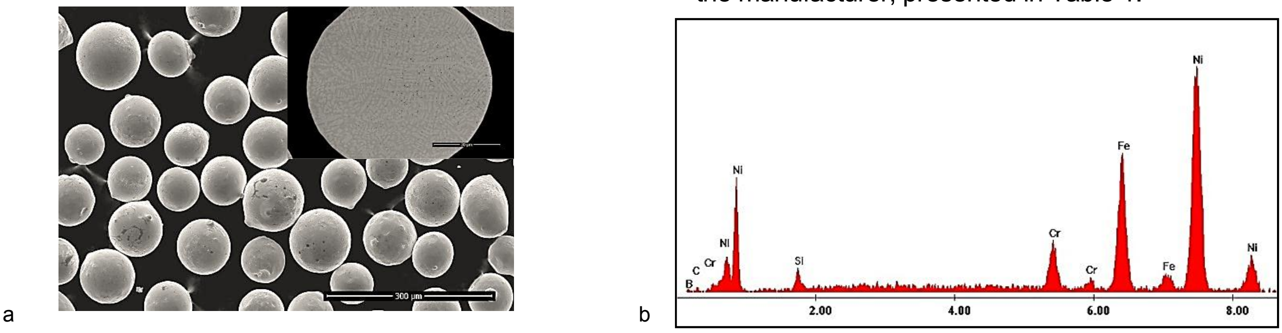
2.4. Wear testing

Pin on disc tests were performed at room temperature on mirror like polished samples using a 6mm WC-Co ball as counterpart under 10N load at 250 rot/min sliding speed. The track diameter was 12 mm and the total sliding distance was 500m. The wear scars were investigated with an Olympus LEXT 3D laser microscope, SEM and EDX. After each test the samples were cleaned and the material losses were measured. The wear rate was calculated according to ASTM G99-05 (2010).

3. Results and discussion

3.1. Powder characterization

The morphology of the powder is shown in Figure 1a and reveals spherical particles characteristic to gas atomization manufacturing. Cross-section of a single powder particle presents fine cellular and dendritic microstructures and some pores might be noticed as well. The EDX spectrum (Fig. 1b) confirms the chemical elements, reported by the manufacturer, presented in Table 1.



a b

Fig. 1 - Morphology of Metco 12C powder and EDX spectrum of a single powder particle
Morfologia pudrei Metco 12C şi spectrul EDX obținut în cazul unei singure particule.

3.2. Coating microstructure, chemical and phase composition

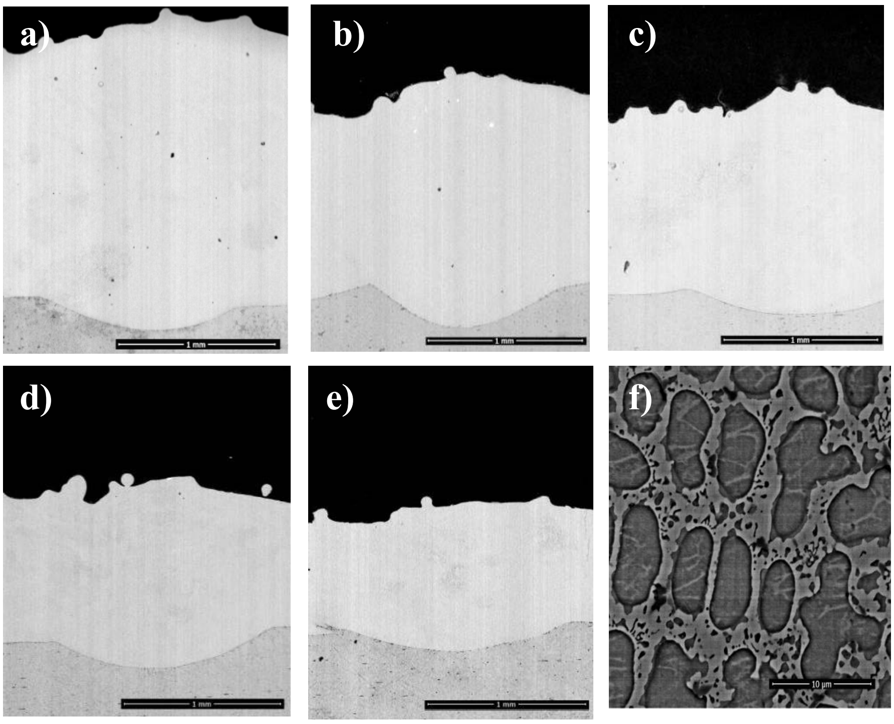


Fig. 2 - SEM micrographs of polished cross-sections of NiCrBSi laser cladded coatings of Sample 1 (a), Sample 2 (b), Sample 3 (c), Sample 4 (d), Sample 5 (e) and Sample 6 (f) / *Micrografiile SEM obţinute pentru secţiunile transversale ale acoperirilor NiCrBSi pentru Proba 1 (a), Proba 2 (b), Proba 3 (c), Proba 4 (d), Proba 5 (e) şi Proba 6 (f).*

Figure 2 presents the microstructures of the NiCrBSi laser cladded coatings obtained using the deposition parameters from Table 2. As it can be observed all the cladded coatings are dense without cracks and a good adhesion with the substrate might be noticed which indicates that the feedstock material was completely melted. To obtain qualitative depositions a good metallurgical bond is required between the layers and substrate material which must to be provided by a certain degree of dilution. Dilution quantifies the relative amount of melted substrate material mixed with the new coating during cladding [9]. The differences between the process parameters lead to coatings with different thicknesses. It might be noticed that the thickness of the cladded coating decreases as the deposition speed increasing .The coatings structure do not differ across their thickness. All the coatings are dense and almost free of pores. At higher magnification the etched microstructure revealed a dentritic structure with intermetallic laminar eutectic phase within the dendrites (Figure 2f).

Thickness, micro-hardness, porosity measurements and dilution results of cladded NiCrBSi coatings are presented in Table 3. Thickness measurements were performed on SEM images and the average value was calculated. Hardness measurements were performed along a straight line for all the coatings. The hardness decreased as the coatings became thinner due to the diffusion of iron from the substrate that was melted during cladding. The reduced amount of porosity determined on 10 SEM images at 1000x magnification for each coating was less than 1% indicating compact and dense coatings. The diffusion was calculated on SEM micrographs using a non-destructive method [5]. The deposition/cladded area (Ac) and the melted area (Am) were determined on a length of 1,5 mm and the dilution was calculated using the following formula: Dilution = Am/(Ac+Am)*100. It might be noticed that the dilution percentage increases with the deposition speed, as the coating became thinner.

Table 3

Values of the thickness, micro-hardness and porosity measurements
Valorile grosimilor, micro-durităţilor şi a porozităţilor

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Thickness [µm] *Grosime*	1.82 ± 0.21	1.49 ± 0.18	1.18 ± 0.14	0.94 ± 0.15	0.77 ± 0.11
$HV_{0.3}$ *Duritate*	513.4 ± 10.3	481.2 ± 10.7	463.5 ± 16.8	442.2 ± 10.2	411 ± 3.4
Porosity [%] *Porozitate*	0.62 ± 0.88	0.9 ± 0.1	0.56 ± 0.48	0.05 ± 0.15	0.07 ± 0.17
Dilution [%] *Diluţie*	5.93	7.65	9.98	11.67	15.8

The phase compositions of the feedstock powder and cladded coatings were compared by means of X-Ray diffraction technique (Figure 3). Due to the fact that there were noticed no significant phase modifications for the deposited coatings only one pattern was presented. The complexity of the NiCrBSi alloy enables to obtain different types of borides, carbides and silicides [10]. The main structural phases indentified for the powder were: NiB (reference pattern 00-006-0567), NiCr (reference pattern 00-026-0429) and CrB (reference pattern 00-009-0361). Besides these phases the cladded coatings presented also NiSi. The difference in the XRD peak widths and also their small shift between the powder and coatings is given by the different level of crystallinity.

3.3. Dry sliding wear test

The Cof as a function of sliding time is presented in Figure 4. The friction coefficient was measured for all the cladded coatings and the average values were calculated. After pin-on-disk test wear losses were measured using a high precision scale. Before measurements, the samples were blasted with compressed air to remove particles from the surface. Due to similar values and to avoid curves overlapping only the representative graphs were presented for Sample1, 3 and 5. At the beginning of test the value of Cof increased for all the coatings. Among the coatings, the Cof for Sample 5 started to increase after 15 min of test which might be caused by the highly adhesive micro-contacts between the surface and counter-body. The lowest Cof was attributed to Sample 1, which started to decrease after 15 min and became stable.

The average Cof values and wear rates K are presented in Table 4.

Table 4

Results of pin-on-disk measurements

Rezultatele măsurătorilor pin-on-disk

	CoF function value (average)	K [mm^3/Nm]
Sample 1	0.589392	$1.1 \cdot 10^{-4}$
Sample 2	0.595781	$1.4 \cdot 10^{-4}$
Sample 3	0.671623	$1.7 \cdot 10^{-4}$
Sample 4	0.625766	$2.3 \cdot 10^{-4}$
Sample 5	0.455103	$3.3 \cdot 10^{-4}$

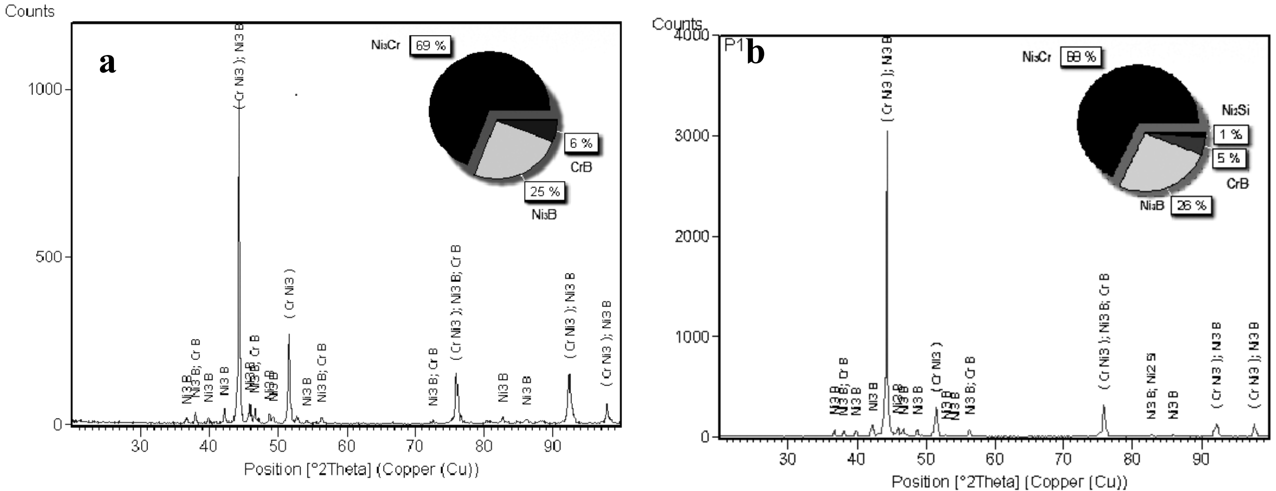


Fig. 3 - XRD of feedstock powder (a) and cladded coating (b) / *Difractogramele obținute în cazul pudrei utilizate (a) şi a straturilor obținute (b).*

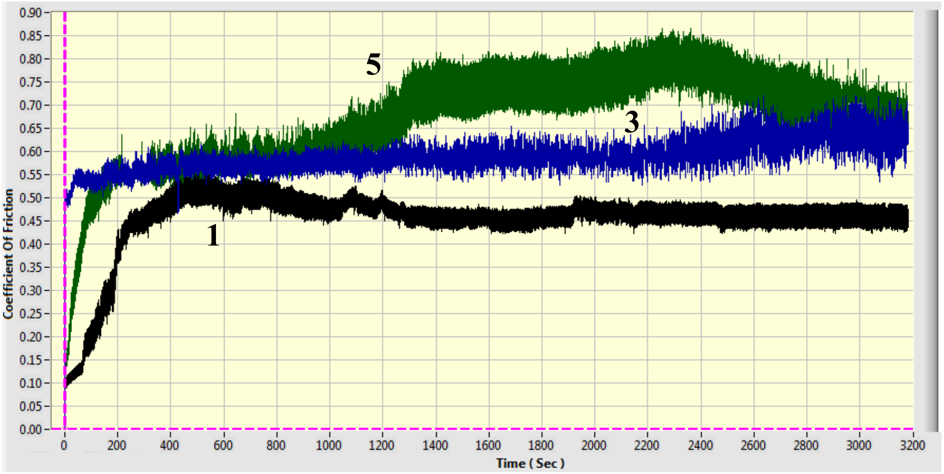


Fig. 4 - Cof function of sliding time of NiCrBSi laser cladded coatings for samples 1, 3 and 5 / *Cof funcție de timpul de alunecare pentru straturile NiCrBSi ale probelor 1, 3 şi 5.*

Table 5

Wear track measurements / *Măsurătorile efectuate pe urmele de uzură*

	Sample 1	**Sample 2**	**Sample 3**	**Sample 4**	**Sample 5**
Track width [µm]	403.75	533.55	573.09	785.99	1018.37
Track depth [µm]	40.04	56.54	43.06	58.13	66.49

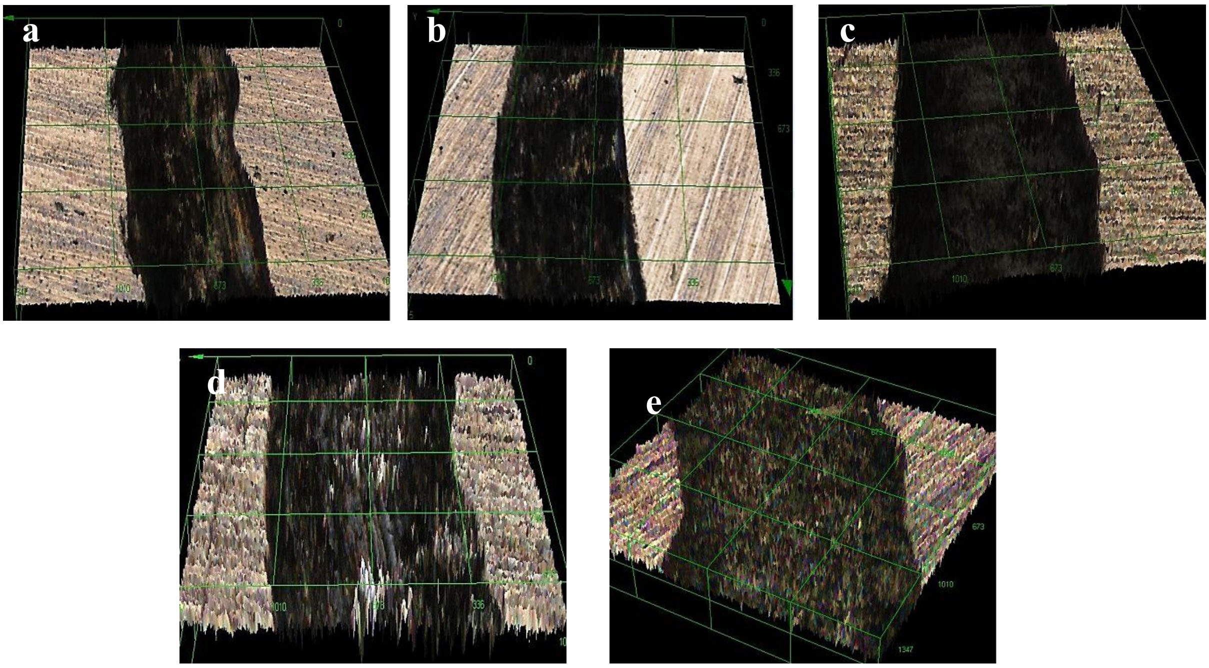


Fig. 5 - 3D profiles of wear tracks of Sample 1 (a), Sample 2 (b), Sample 3 (c), Sample 4 (d), Sample 5 (e) and Sample 6 (f)
Profilul 3D al urmelor de uzură pentru Proba 1 (a), Proba 2 (b), Proba 3 (c), Proba 4 (d), Proba 5 (e).

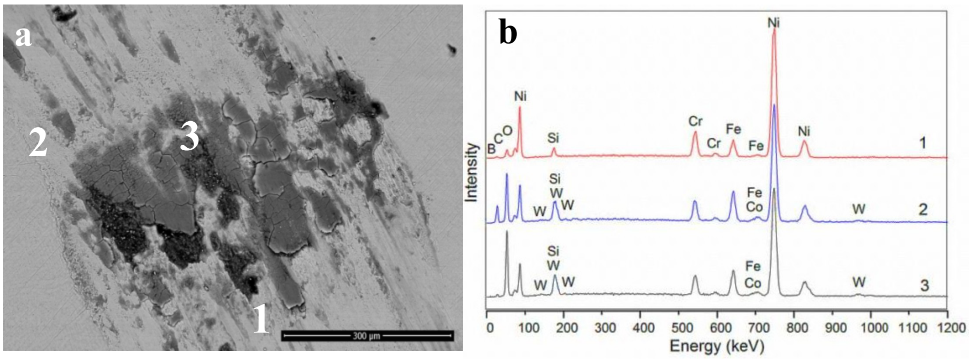


Fig. 6 - SEM micrograph of wear track (a) and EDX spectra of different areas (b)
Micrografiile SEM ale urmelor de uzură (a) şi spectrele EDX ale diferitelor zone (b).

The smallest material loss was calculated for sample 1 which had the higher hardness and the lowest dilution in comparison with the other samples. The dilution grade influenced the hardness and also the wear resistance. Higher dilution leads to smaller hardness and lower wear resistance. Table 4 presents the wear tracks width and depth measured with a laser microscope and Figure 5 presents 3D wear tracks of the coatings. The obtained results are well correlated with the wear resistance behaviour. Among the coatings, Sample 1presented the narrowest wear track and smallest wear depth.

Due to high rotation speed and applied load without lubricant the sliding wear is considered to be mainly adhesive wear. Detachments of coatings formed on all the samples (Figure 6). The grooves are caused by detachments of coating which are basically debris particle which act as an abrasive third body between the ball and coating. The darker areas indicated higher oxidation, according to the EDX analysis, which was caused due to higher temperatures occurred during friction. Also the presence of tungsten and cobalt might be noticed on the wear track which means that particle removal occurred also at the surface of counter-body and the particle debris were embedded at the surface of wear tracks.

Among the coatings, Sample 1 presented higher hardness, the lower dilution and the best wear behaviour.

4. Concluding remarks

NiCrBSi coatings were produced on steel substrate by laser cladding technique. The influence of speed deposition and material dilution on the tribological behaviour of the coatings was investigated.

It has been found that as the deposition speed increased from 16 cm/min to 34 cm/min the coatings thickness decreased from 1.82 mm to 0.77 mm.

The hardness and the wear properties were also influenced by the deposition parameters the material dilution being different and affecting the coatings properties. Higher dilution was calculated at the thinnest coating (highest deposition speed).

The highest hardness and the best sliding wear resistance were recorded at the smaller dilution grade. In opposite the coatings obtained at higher deposition speed had the worse mechanical properties.

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