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TINMICROHARDNESS CHARACTERISTICS OF METAL MATRIX COMPOSITE LAYERS OBTAINED BY LASER CLADDING

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Necesitatea societății industriale actuale, pentru materiale compozite specifice pentru fiecare tip de aplicație în parte, este satisfăcută de către dezvoltarea tehnologiei de depunere cu laser. Prezenta lucrare oferă însemnări relevante privind metodologia optimizării experimentelor în ceea ce priveşte obținerea straturilor compozite bazate pe WC-Co prin depunere cu laser. Studiul efectuat accentuează modul în care variația parametrilor procesului influențează caracteristicile de microduritate ale straturilor depuse. Analiza SEM şi EDS a evidențiat extinderea fenomenului de diluție şi dispersia carburilor în cadrul stratului depus, în funcție de valorile parametrilor procesului.

The industry's current need for application-oriented composite materials is currently fulfilled by the development of laser cladding technology. The present paper offers relevant notes regarding an experimental approach to the design optimization of experiments regarding WC-Co based layers obtained by laser cladding. The manner in which the parameter's variation influences the microhardness characteristics of the cladded layers is emphasized in the current study. The SEM and EDS analysis revealed the extension of the dilution phenomenon and the dispersion of the carbides within the composite layer depending on process parameters.

Keywords: metal matrix composites, cerment, laser cladding, microhardness.

1. Introduction

Presently one of the pressing problems of modern engineering is the production of special and durable coatings on surfaces of materials. Laser technology provides a unique way to modify the surface of materials (transformation hardening, alloying, cladding, etc.) and achieve superior surface properties [1]. The basics of laser cladding include a firm understanding of laser

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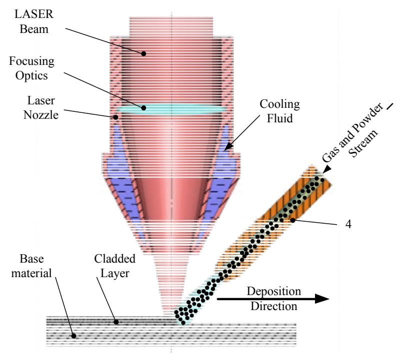
light and the interaction between the laser beam and the materials used in the process. Laser cladding is an interdisciplinary technology utilizing laser technology, computer-aided design and manufacturing (CAD/CAM), robotics, sensors and control, and powder metallurgy. The key components that influence the overall quality of the process are integrated in order to form the laser cladding system.

Laser cladding is one of several ways to improve the surface properties of metallic mechanical parts, such as hardness and the resistance against wear and corrosion. This led to the development of laser induced surface improvement with the purpose of manufacturing and/or remanufacturing of mechanical parts that are subjected to very harsh working conditions. The rapid industrial acceptance of this process is due to the fact that industrial lasers are a controllable heat source, which leads to a very good control of the heat input to the work piece resulting in low dilution of the coating layer (mixing of the coating with the substrate), low thermal stresses and low distortion. Conventional methods, such as submerged arc welding or shielded gas metal arc welding, require significantly higher values for the heat input to the part, greater dilution, the potential of greater distortion of the part, and a rougher surface that requires additional processing. Non-welding methods, flame spraying and plasma spraying, produce coatings that are mechanically rather than metallurgically bonded to the surface. Generally speaking, coatings produced by these methods are thinner than coatings produced by laser or arc welding processes [2].

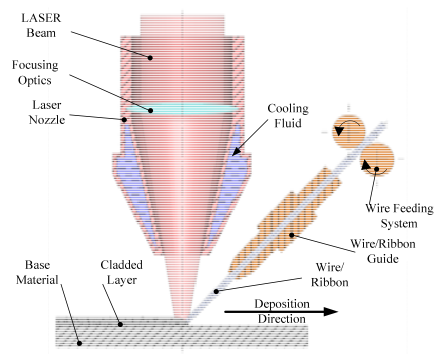
In the case of depositing a layer of composite material with a high wear resistance, regardless of the process used, a few fundamental requirements have to be taken into consideration, such as: the conservation of hardness and strength properties of the reinforcing elements, providing a uniform spatial distribution within the matrix material and creating proper conditions for the formation of strong bonds between the matrix and the reinforcing elements [3].

Laser cladding competes in the world of rapid manufacturing with a large number of other techniques that are in vogue, but only some of them have been used for the production. The processes which have mainly been employed for fabricating WC-Co based composite layers are: Selective Laser Sintering/Melting (SLS/SLM), Laser Engineered Net Shaping (LENS), Laminated Object Manufacturing (LOM), Stereo Lithography (SL), Fused Deposition Modeling (FDM), Three Dimensional Printing (3DP) and Ultrasonic Consolidation (UC). Laser cladding is most similar to the SLS and LENS techniques as they are also powder and laser-based techniques; the main difference between the two processes is the way the powder is deposited. The fabrication of composite in LENS is similar to SLS with regard to laser–powder interaction [4].

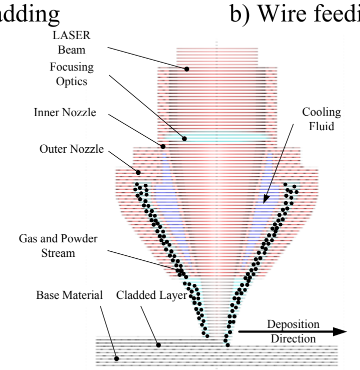
Laser cladding materials can be delivered by powder or wire/ribbon, corresponding feeding methods called powder feeding or wire feeding.



a) Side powder laser cladding



b) Wire feeding laser cladding



c) Coaxial laser cladding

Fig. 1. Laser cladding process schematic.

When the powder stream is injected off-axis (Fig. 1.a) from the laser beam, the change of substrate movement direction leads to completely different local cladding conditions. When the powder stream is delivered coaxially (Fig. 1.c) with the laser beam, all directions of the substrate movement in a plane perpendicular to the laser beam are equivalent. The coaxial laser cladding process is thus independent of the cladding direction [5]. Therefore, it is possible to produce equivalent tracks independently of the moving direction of the work piece.

2. Experimental procedure

2.1. Materials

One of the best methods by which the mechanical properties of the deposited layer can be improved is reduction of the grain size of the material. In order to achieve a fine microstructure in the WC-Co based layers, a microcrystalline WC – 17wt. % Co powder, with an average of 45 µm grain size, was used as the feed stock powder for this work. The powder is a spheroidal, agglomerated and sintered powder (SR EN 1274:2005) made by Sulzer Metco with the commercial denomination of WOKA 3202; its composition is presented in table 1.

Table 1.

Chemical composition of the WOKA 3202 powder

Material	Chemical composition			
	Co [%]	C [%]	Fe [%]	W [%]
WOKA 3202	16.0 - 18.0	4.8 - 5.3	Max 0.2	Bal.

The base metal consists of a general use non-alloyed structural steel plate, S235 (SR EN 10025:2005).

2.2. Process description

A 3300 W continuous wave Rofin, Nd:YAG laser (Fig. 2. a) system was used to provide the heat source to generate the molten pool. During this process, powder was delivered coaxially in a gas stream of argon, through nozzles, into the molten pool. The movement of the laser cladding head, where the laser source and nozzles are located, was assured by an ABB IRB 4400 anthropomorphic robotic system (Fig. 2. b) with a spatial resolution of 0.1 mm (fig.1), thus providing a controlled deposition of a thin line with finite width and height (on the order of 1 mm).

a) laser power source b) ABB IRB 4400 robot

Fig. 2. Laser cladding equipment

In the present study, the cladded layer consists of a 25 mm long single track. In order to avoid any contamination with impurities from the atmosphere, from the resulting process powder spatters, the test sample was enclosed in a custom build chamber filled with argon. The reason for choosing Ar as the protective gas is due to the fact that it is an inert gas.

Fig. 3. Experimental set up for laser cladding in a controlled atmoshpere

The laser cladding head (Fig. 3) was mounted vertically tilted by 5º on the travel direction to avoid the reflection of the laser beam on the substrate to the fiber optics of the head. The laser beam had a TEM_{00} profile, and the spot size was varied by changing the position of the laser beam waist (focal point) with respect to the work surface.

2.3. Laser cladding parameters

In sintered materials, the WC grains tend to touch one another and form a continuous "skeleton" of carbide, with the cobalt binder occupying the spaces between the carbide grains. In the case of laser cladded coatings, this is usually not the case, and the carbide particles tend to be more or less discrete in the matrix [4].

Similar to other cladding materials, the WOKA 3202 tungsten based powder relies upon the transferring of tungsten carbide particles from the cladding powder to the overlay and on the formations of suitable WC-rich hard phases during the molten pool solidification. Therefore, it is important to limit the heat input of the cladding process in order to facilitate an optimum formation of tungsten carbide particles.

The variation of the experimental parameters was realized in complaisance with two L9 Taguchi arrays, this method of parameter variation was chosen due to the small number of experiments but with a high sensitivity to laser power density values.

The parameters used for the experiments are presented in table 2.

Table 2.

Laser cladding parameters

Sample code	Parameters					
	SD* [mm]	**PFR* [g/min]**	**LP* [W]**	**CS* [mm]**	**PD* [kW/cm²]**	**HI* [J/cm]**
CoAx[s]1.1	0.6	4	330	5	116.77	93.5
CoAx[s]1.2				6.5	116.77	71.92
CoAx[s]1.3				8	116.77	58.44
CoAx[s]2.1			396	5	140.13	112.2
CoAx[s]2.2				6.5	140.13	86.31
CoAx[s]2.3				8	140.13	70.13
CoAx[s]3.1			462	5	163.48	130.9
CoAx[s]3.2				6.5	163.48	100.69
CoAx[s]3.3				8	163.48	81.81
CoAx[s]4.1		8	330	5	116.77	93.5
CoAx[s]4.2				6.5	116.77	71.92
CoAx[s]4.3				8	116.77	58.44
CoAx[s]5.1			396	5	140.13	112.2
CoAx[s]5.2				6.5	140.13	86.31
CoAx[s]5.3				8	140.13	70.13
CoAx[s]6.1			462	5	163.48	130.9
CoAx[s]6.2				6.5	163.48	100.69
CoAx[s]6.3				8	163.48	81.81

* SD – Spot Diameter; PFR – Powder Feed Rate; LP – Laser Power; CS – Cladding Speed; PD – Power Density (Irradiance); HI – Heat Input.

3. Results

3.1. Microhardness results

The $HV_{0.2}$/15sec microhardness examination was performed on the characteristic areas of transversal cross-section of the cladded specimens: the clad layer, the heat affected zone, and the base metal according to the measurement scheme presented in figure 4.

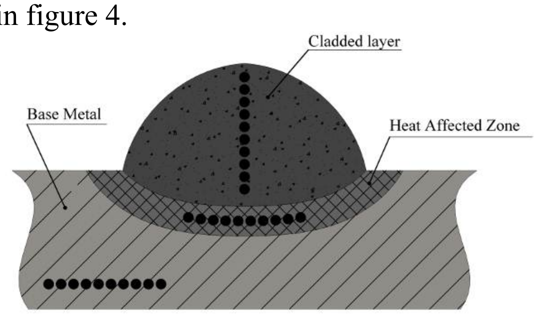
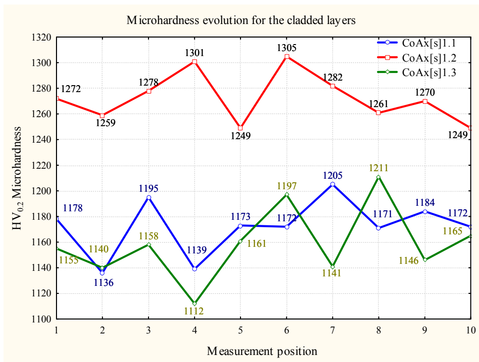
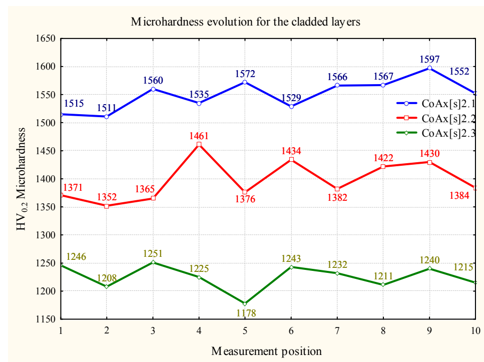


Fig. 4. Microhardness measurement scheme

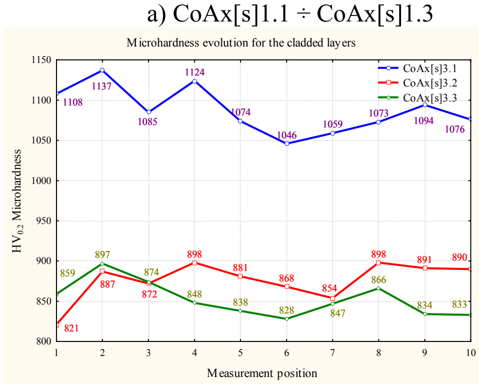
In the base material case, the micro-hardness field has an average value of 166 HV0.2, with a standard deviation (SD) of 1.76, and a coefficient of variation (CV) of 1.06, taking into consideration the fact that the values for the SD and the CV are given by the micro-hardness tester. The microhardness values of the cladded layers have a higher coefficient of variation because of the irregular manner in which the carbide particles are distributed within its mass.



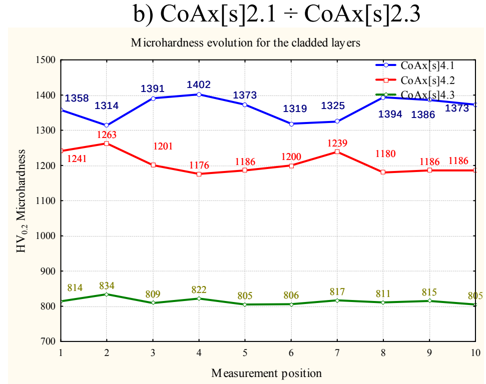
a) CoAx[s]1.1 ÷ CoAx[s]1.3



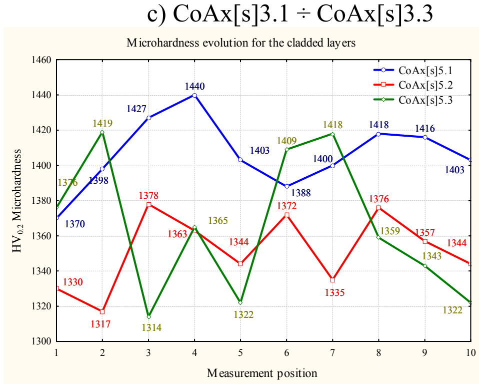
b) CoAx[s]2.1 ÷ CoAx[s]2.3



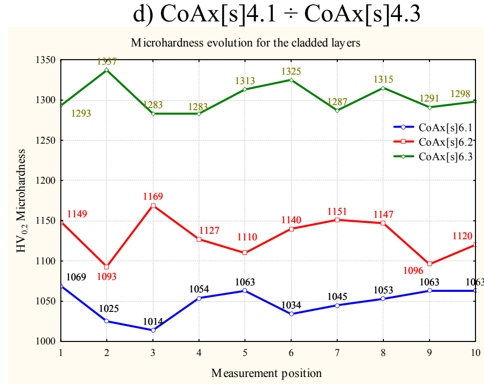
c) CoAx[s]3.1 ÷ CoAx[s]3.3



d) CoAx[s]4.1 ÷ CoAx[s]4.3



e) CoAx[s]5.1 ÷ CoAx[s]5.3



f) CoAx[s]6.1 ÷ CoAx[s]6.3

Fig. 5. The microhardness values of the cladded layers

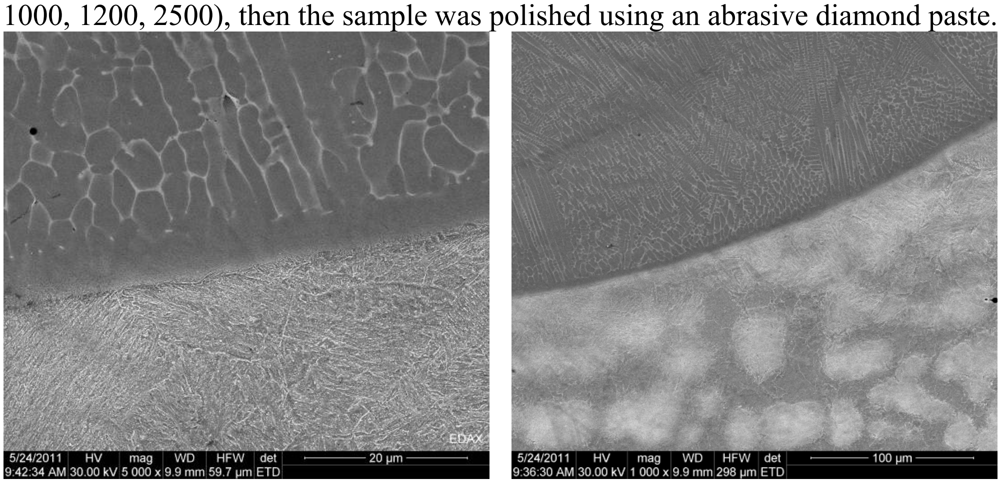
The cladded layers hardness is influenced by the speed of the process in the following manner:

- If the cladding speed has low values, then the heat input of the process is higher and the thermal effect on the powders is more intense, and the particles can be better dissolved into the mass of the layer. In this case the strengthening effect can be obtained by two distinct mechanisms, namely: particle embedding and solid solution hardening;
- At higher values for the cladding speed (lower values for the heat input), the consolidation effect is solely due to the presence of undivided tungsten carbides bonded by the Co.

Except for the CoAx[s]5.1 ÷ CoAx[s]5.3 samples where the influence of the cladding speed does not have a significant effect on the hardness values because the overall effect of the parameters is good. The highest value for the microhardness is 1597 $HV_{0.3}$ for the CoAx[s] 2.1, setting the processing window around the values used to obtain this sample.

3.2. Microscopic analysis

After laser cladding, the samples were cut-off using a special cutting disc, at low cutting speeds and continuously cooled with water and lubricant in order to avoid any microstructural changes (quenching effects) that can occur superficially due to a supplementary thermal cycle. The surface preparation of the sample involved the cleaning of the sample surface in order to remove any extraneous or undesirable material or deposit, the grinding and polishing of the surface using silicon grinding paper with successive granulations (Grit. No.: 400, 600, 800, 1000, 1200, 2500), then the sample was polished using an abrasive diamond paste.



a) CoAx[s]5.1 b) CoAx[s]2.1

Fig. 6. SEM analysis of the interface between the cladde layer and the base material

In the absence of cobalt, pure WC particles, do not melt under standard atmospheric conditions, instead they decompose into a liquid phase and graphite at a temperature of above 3050 K. At temperatures much lower that this value, it has been noticed the presence of a brittle η phase and dissolution of WC in the cobalt that acts like binding agent [6]. This fact is important in the laser cladding process due to the fact that the temperature achieved in the laser beam is high enough to decompose the WC directly if the power density has a high-enough value, but certainly could do so through the reaction of WC with the cobalt binder if the power density is lower.

In the case of the CoAx[s]2.1 sample, the grain structure of the heat affected zone is coarse, due to the high value of the laser beam's irradiance. The fact that the test sample is subjected to a severe thermal cycle leads to the formation of a Widmanstatten structure in the vicinity of the diffusion line.

The hardness of the heat affected zone does not have significant variation with the increase of power density, and its values distribution does not follow a specific pattern.

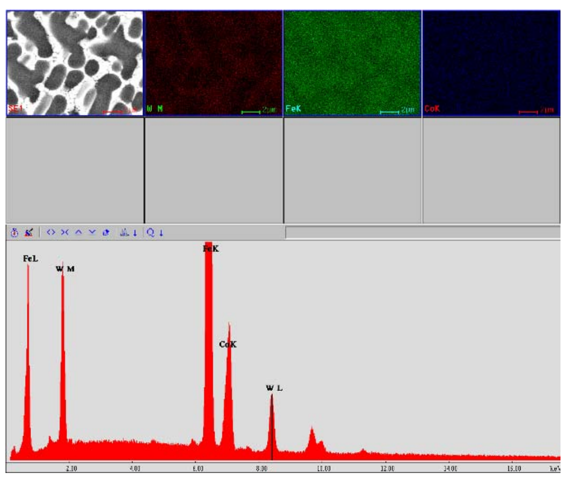


Fig. 7. EDS analysis of a typical structure for the cladded layers presented in this study

The EDS analysis of the test samples reveals a qualitative distribution of chemical components, being able to examine if there is uniformity of this distribution. Another important aspect is that areas rich in certain chemical elements can be detected by means of this analysis. Fig. 7 depicts a uniform distribution of tungsten carbide in the microstructure of the test sample.

The tungsten carbide does not have a stable molten phase; it transforms into an embrittling phase with high carbon content. Therefore, it is very difficult to successfully process these carbides in the extremely high-temperature, oxidizing / decarburizing conditions generated during laser cladding.

4. Conclusions

A series of composite layers reinforced by tungsten and chromium carbides have been obtained by means of controlled atmosphere laser cladding technology.

The microhardness results obtained in this study have revealed the influence of the processing speed on its values

Even though in general laser processing technologies, the power density is the key factor, in cladding application a more direct effect can be observed by varying the heat input value, as it is done in this paper. At high heat input values the tungsten carbide tends to grow, thus improving the consolidation effect upon the microstructure of the cladded layer. Further investigations in terms of microhardness and tribological properties will be achieved for further papers

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