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CHARACTERISATION OF METALLIC LAYERS DEPOSITED THROUGH THERMAL SPRAYING

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The characterization of the metallic layers deposited through thermal spraying can be done with different destructive and nondestructive techniques. In this article the authors describe ultrasound immersion. The purpose of the paper is to characterize the quality of thermal spray deposited layer adhesion to the base material. The parameters of the technological process of deposition through thermal metal spraying which have been taken into consideration to establish the quality of adhesion are deposited material granulation, deposition pressure, nozzle diameter of the torch used for deposition, spraying distance, and deposition angle. A series of tests to determine the influence of changes of certain parameters of technological process deposition thermal metal spraying on the quality of adhesion were performed.

Keywords: metallization, ultrasounds, nondestructive examination.

1. Introduction

Continuous development of modern industrial society, enhancing of operating modes, and the use of concentrated energies cause the need for equipment capable of operating for a long time and in hard working conditions. The wear of machine components led to the development of reconditioning technologies. The reconditioning allows bringing the part to its original size by applying a layer of filler of a material having superior wear resistance.

Technological advantages. The base piece undergoes a moderate heat for metal spraying. Its temperature will not exceed 100÷120°C. In this case, the appearance of strain or internal stresses in the piece is avoided.

Economic advantages. Spray metallization costs are lower than for other methods, except for pulse metallization. Metal spraying is done with small investments; the necessary equipment is included in most plants [1]. Therefore,

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metal spraying is one of the important solutions for the problems which involve material savings.

Specific defects of the metallization layers deposited by thermal spraying are the followings: non-adhesions, partial flaking, cracks, pores, voids, nonmetallic inclusions, and oxide films at the interface of deposited material - base material and between granules. From these, the most delicate issue is the one of quantitative assessment of adhesion. An adhesion, even precarious, is difficult to highlight and to rate quantitatively.

Most faults can be highlighted using different techniques, as: visual examination, ultrasound examination, infrared examination, acoustic emission examination [5] .

All the above methods are effective in detecting the vast majority of faults. In terms of adhesion, these methods can determine whether adherent or non-adherent layer is deposited on the base material, but cannot appreciate the quality of adhesion and adhesion strength.

Ultrasound techniques, infrared and acoustic emission radiations have the ability to evaluate quantitatively the adhesion given by the "quasi-continuity" of material at the interface base material - deposited layer by thermal spraying.

2. Methods for assessing thermal deposited layers

The nondestructive defectoscopy allows the faults detection of the deposited layer and also the faults that appear at the interface deposited material-base material, without affecting the integrity and part properties. It can detect areas with lack of adherence, partial exfoliation, cracks, voids etc. Sprayed layers are by definition porous, so the problem of the appearance of pores is not taken into account [2]. The most used defectoscopy techniques for thermal sprayed layers are: ultrasound examination (US) and infrared examination (IRT).

Both methods are efficient when detecting the majority of faults. From the adherence point of view, with these methods one can assess whether the deposited layer has adherence or not to the base material, but the quality of the adherence cannot be assessed.

2.1 Ultrasound examination of thermally deposited layers

A typical US control system consists of several functional units, such as generator/pulse receiver, transducer, and display devices. The generator/receiver is an electronic device which produces high voltage pulses. The led by pulse transducer generates high frequency ultrasonic energy. The sound energy is introduced through materials by wave propagation. A part of the energy will be reflected back to the surface when a discontinuity appears in the wave path. The reflected signal is converted into electrical signal and then is displayed on the screen (see fig. 1).

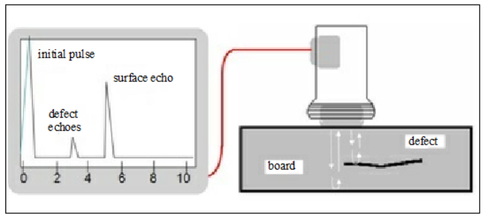


Fig. 1. Principle scheme of the ultrasound examination.

The US is based on time-varying deformations or vibrations in materials, which is generally referred to as noise. All substances are made of atoms. These atoms are put into motion by the vibrations, according to their position of equilibrium. At atomic level, there are many different vibration patterns of movement between them. Depending on the spreading way, ultrasounds can be:

- Longitudinal - the direction of the environment particles oscillation is parallel to the direction of wave propagation;
- Transversal - the direction of the environment particles oscillation is perpendicular to the direction of wave propagation;
- Surface - with a more complicated trajectory of particles, which propagates only on the surface layer of the body [3].

3. Experimental procedure

The quality characterization of the deposited layers is the last thing done. Daily examination of the layers quality is achieved by visual inspection and using microscope observations of the sample cross section. The deposited layer may have faults that cannot be observed only using the two above mentioned methods.

For this reason, nondestructive examination techniques were developed by pioneers in this field, namely Bucklow (1980), Steffens (1984) and Crostack (1986).

For the layers deposited by thermal spraying, the following nondestructive examination method is used:

- Acoustic method such as acoustic emission (EAT) or ultrasound (US).

This method must be applied to large areas of examination, and the examination results must be interpreted on the spot in order to be accepted for industrial conditions.

In the conducted experiments, for the base material of the cylindrical samples, a quality carbon steel material OLC 35 type was used.

The chemical composition and the cylinder material properties are presented in table 1 and 2.

Table 1

Chemical composition of OLC 35 material

Material	Chemical composition							
	C [%]	Si [%]	Mn [%]	P [%]	S [%]	Cr [%]	Ni [%]	Mo [%]
OLC35	0,339	0,308	0,88	0,018	0,019	0,105	0,081	<0,0099

Table 2

Mechanical properties of the steel OLC 35 at room temperature

Material	Hardness in annealed condition HB	Yield stress Rp_{02} [N/mm^2]	Breaking limit Rm [N/mm^2]	Elongation A_5 [%]
OLC35	183	275	490-640	21

The analysis of the chemical composition was conducted on a sample of material. This type of analysis is performed by optical emission spectrometry using a spark spectrometer named SPECTROMAXx. The base material has a fully ferrite - pearlite structure. This structure can be observed in fig. 2.

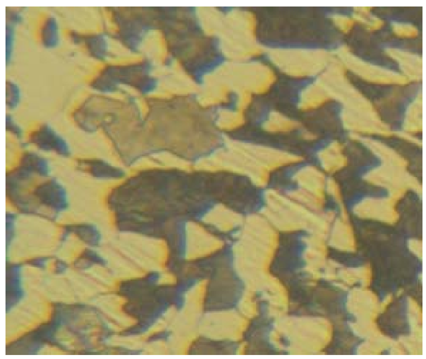


Fig. 2. Base material structure: lamellar ferrite and pearlite.

Four OLC35 cylindrical samples were used for experimental investigations. In order to restore these parts, a series of steps to prepare the surface were taken into account. The characteristics of the deposits made through thermal spraying metallization were analyzed by metallographic analysis and micro-hardness measurements. The metallic substrate consists of cylinders with size 90 x 40 mm with variable roughness in the range $6.3 \leq Ra \leq 12.5$ obtained through machining. The deposited material is made of bearing steel RUL1 in wire form. To increase the adherence of the deposition to the base layer, the surface was restored through blasting using different grains, as shown in table 3.

Table 3

Blasting with different materials of the 7 OLC 35 parts

Sample / Material	Siliceous sand	White cast iron shots	Silicon carbide	Corundum (Al_2O_3)
P1	X	-	-	-
P2	-	X	-	-
P3	-	-	X	-
P4	-	-	-	X

We wanted to obtain different adhesions to the base material by changing the blasting material. The adherence is classified as shown in table 4.

For obtaining the differential adhesion the blasting parameters were also varied, namely the blasting distance (see table 5).

Table 4

Normal adhesion obtained on the cylindrical samples

Sample / Adherence	Week	Average	Good	Very good
P1	X	-	-	-
P2	-	X	-	-
P3	-	-	X	-
P4	-	-	-	X

The material used for arc spraying is presented in form of wire, mark S105Cr1 (Rul1) with a diameter of 1,2 mm having the following characteristics: highly resistance to wear, hardness - 350 ... 420 HB, can be machined with carbide tools, good finishing.

Table 5

Blasting parameters for cylindrical OLC 35 samples

Parameters / Probe	Blasting particles granulation [mm]	Blasting pressure [MPa]	Blasting nozzle diameter [mm]	Blasting distance [mm]	Blasting angle
P1	0.8	0.5	10	100	90°
P2	0.8	0.5	10	95	90°
P3	0.8	0.5	10	90	90°
P4	0.8	0.5	10	85	90°

Arc metal spraying consists of melting the wire-electrode filler material with electrical arc which is formed between the two electrode wires. This melted material is then sprayed using the compressed air on the reconditioned piece surface [4]. For conducting the experiments, a metal spraying plant with two-wire arc-electrode-Arc 140 S350-CL was used. It consists of a power supply, control system panel, power supply with compressed air, drums coils of wire-electrode, metalizing gun, absorbing hood and filter-ventilation system. The metallization process parameters during deposition with electrical arc are presented in table 6.

Table 6

Process parameters of metal spraying during the deposition

Parameters	General values	Values obtained to metallization of the parts
Wire-electrode diameter, d [mm]	1…2	1,2
Ignition and shortcut frequency [Hz]	100	100
Arc voltage, U_a [V]	20…40	20
Arc temperature [K]	6100	6100
Spray gas nature	Air, nitrogen, inert gas	Air

Spray gas pressure [MPa]	0,4…0,65	0,5
Spray distance, L [mm]	50…150	100
Working atmosphere	Air, active/inert gas, void	Air
Spray gas flow [l/min]	20…1000	460
Molten particle velocity [m/s]	150	150

Cylindrical samples were metalized on the entire outer surface, except their heads, as shown fig. 3.

Fig. 3. Cylindrical OLC 35 samples.

4. Experimental results

4.1 Micro-hardness measurements of the thermal spraying deposited layers

Micro-hardness test allows punctual estimation of hardness in different areas: deposited material, interface deposited material- base material and the base material. The surface of the part subjected to micro-hardness determination was prepared using metallographic procedures, then it was attacked with reagents specific for base material. Within the experimental program, the measuring range $HV_{0.1}$ was selected, one in which indentations were made with a force of 1.96 N for 10 s.

Microhardness measurements were performed on the base material, interface and deposit, as in Figure 4.

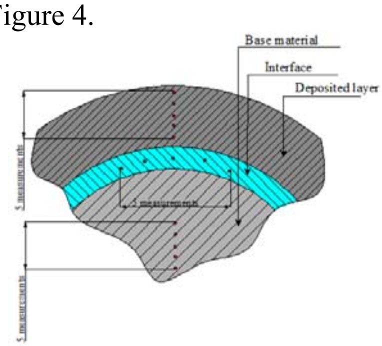


Fig. 4. Measurements scheme of microhardness

The tests were realized in the Machining Laboratory, IMST Faculty, TMS Department. The experimental set-up and the technical characteristics are presented in Figure 5.

Technical Characteristics	
• Magnification power	400X, full automated, with display of the fingerprint on screen
• Measuring range	98,7; 245,2; 90,3; 980,7 Nm; 1,96; 2,942; 4,903; 9,807; 19,61 N (HV 0,01; 0,025; 0,05; 0,1; 0,2; 0,3; 0,5; 1
• Effective display area	250 µm (la 40X)
• Resolution	0,01 µm (la 400X)

Fig. 5. Shimadzu HMV2TE microhardness tester

The values measured on the cylindrical samples are shown in Figs. 6 ÷ 8.

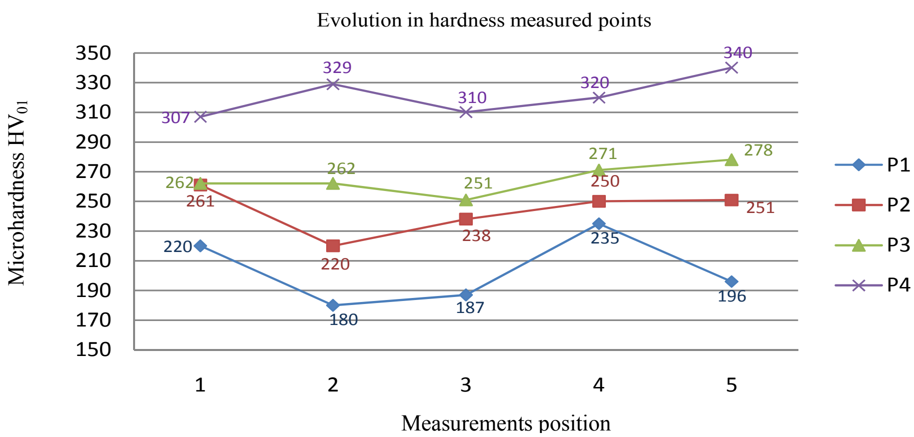


Fig. 6. Evolution of hardness in measurement points in the area of deposited material on cylindrical samples

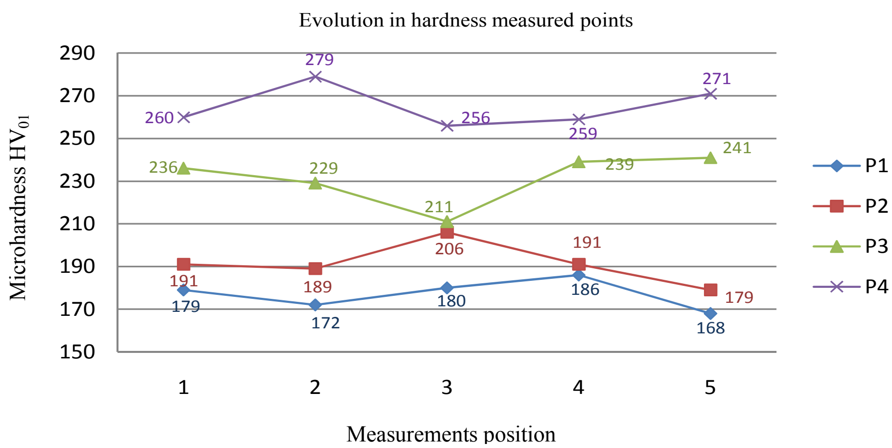


Fig. 7. Evolution of hardness in measurement points in the area of interface on cylindrical samples

4.2 Metallographic analysis of the layers deposited by thermal spraying

To highlight the phases and constituents, a reagent - Nital 2% was used. The equipment used for carrying out the optical microscopy analysis is Neophot 21 electron microscope equipped with a digital camera and a software for metallographic analysis type SCENTIS. This equipment can be found in the INTEC Laboratory. The sample analyzed using the microscopy is the P4 sample. The result is presented in fig. 8.

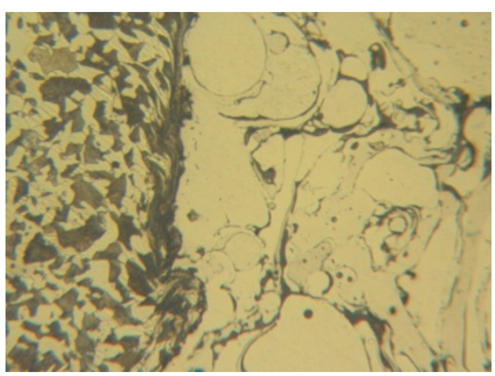


Fig. 8. Microscopy image for the P4 sample- very good adherence.

Fig. 5 shows the appearance of the joint area between the two materials (magnification order x200). The structure is dendritical, and one can see the pearlite and ferrite grains. After the microscopic analysis we could see a high degree of adhesion due to the sample preparation process before reconditioning and also due to the existence of the molybdenum buffer layer.

4.3 Ultrasound examination of the deposited layers by arc spraying

Compared with other methods of nondestructive examination, immersion ultrasound examination method has several advantages which cause its application on thermal spray depositions. Thus, this method of nondestructive examination validates the electronic microscopy and determines the adhesion of the deposited layers following the reconditioning.

The immersion ultrasound method applied to reconditioned parts through arc spraying has very good results in terms of determining the compared adhesion.

The ultrasound examination steps were done according to SR EN 583-1:

- surface preparation exploration;
- control of the base material;
- choice of operating frequency;
- checking and adjusting the equipment;
- baseline establishment.

The outer surfaces of the samples were checked through optic-visual examination so that they do not contain foreign materials which might influence the outcome of the examination. The examination by immersion method is based on the comparison of the amplitude of an echo (A_m) in a series of repeated echoes belonging to a sample made of a material whose coefficient must be determined, and an echo amplitude of higher rank (A_n), from the same series [6,7].

The same conditions for the determination were kept:

- same transducer;
- same equipment;
- same settings;
- same couple;
- same sample thickness;
- same sample surface status.

During the nondestructive examination experiments on the OLC35 cylinder, the axis probe was positioned parallel to the sample axis. In this way the examination was conducted at the interface base material – deposited material.

a) b)

Fig. 9. a) Experimental set-up;
b) OLC 35 samples positioning in the immersion tank.

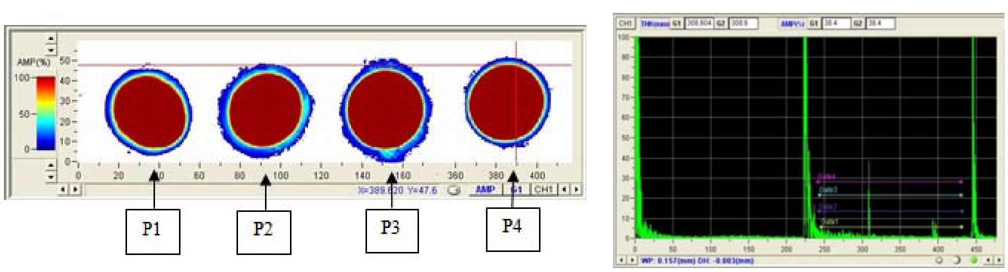
The four samples were placed in the immersion tank as shown in fig. 9 b). Immersion ultrasound examination parameters are presented in Table 7.

Table 7

Immersion ultrasound examination parameters

Parameters	Values
Frequency, f [MHz]	5
Propagation velocity, c [m/s]	5940 (steel), 1480 (water)
Wavelength, λ [mm]	1188
Acoustic impedance, Z [kg/m^{2}s]	46629 (steel), 1480 (water)

After examining the four OLC 35 cylindrical samples, the oscillogram from fig. 10 is obtained. The amplitude was measured around the circumference of the sample at the interface of base material – deposited material at every 10º.



a) b)

Fig. 10. a) oscillogram type C – cylindrical OLC 35 samples P1÷P4;
b) oscillogram type A – cylindrical OLC 35 samples P1÷P4.

The averages of the records for each sample are presented in table 8. These results in a relationship having the following form:

$$A1 > A2 > A3 > A4 \quad (1)$$

The low adhesion of the deposited layer is given by the difference between the signal amplitudes obtained by ultrasound examination. The adherence of the deposited layer is better when the amplitude of the signal is smaller.

Table 8

The average of the records for the OLC 35 cylindrical parts

Sample	Amplitude [%]
P1	90,2
P2	77,5
P3	65,2
P4	57,6

6. Conclusions

- Changing the blasting material, modifying the blasting distance and also the blasting air pressure caused differences between samples regarding the results of adherence of the deposited layer to base material, these results being reflected by the ultrasound investigation;
- Compared to other methods of nondestructive examination, the ultrasound in immersion examination has the advantage of non-contact with the examined part which recommends it for thermal sprayed layers;
- In order to obtain a good adhesion, a buffer layer made of a material different from the material admixture was used (a buffer layer of molybdenum) which contributed to a significant increase of adhesion of the deposited layer to base material, as evidenced in the ultrasound investigation;
- Ultrasound examination has a special penetrating ability allowing examination of thick and very thick sections;
- The technique of ultrasound examination in immersion is particularly advantageous because it requires no contact, and can be applied to the roughened layers deposited by thermal spraying;
- The ultrasound in immersion method applied to restore parts by arc thermal spraying has very good results in terms of determining the degree of adhesion.

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REFERENCES

[1] *Pawlowski L.,* The science and engineering of thermal spray coatings, J. Wiley & Sons, New York, 1994;

[2] *Dumitru G.M. et al.*, Recondiționarea pieselor în construcția de maşini (Reconditioning of parts in machine), Ed. Printech, Bucuresti, 2008 (in Romanian);

[3] *Alexandrina Mihai*, Examinări nedistructive (Nondestructive examination), Editura Printech, Bucuresti, 2009 (in Romanian);

[4] *Subu T.*, Încărcarea prin sudare şi metalizare pentru reconditionarea pieselor şi fabricarea de piese noi 9(Charging welding and plating for the wearing and manufacture of new parts), ISMR, 1992, (in Romanian);

[5] *Shou Cheng Ding et al.,* "The Non-Destructive Measurement Instrument for Material Thickness", in Materials Engineering for Advanced Technologies, 2011, pages 415-420;

[6] *Sharma J.N., Pal M., Chand D.,* ”Propagation characteristics of Rayleigh waves in transversely isotropic piezothermoelastic materials”, in Journal of Sound and Vibration 284, 2005, pages 227–248;

[7] *Laguerre L., A. Grimault and M. Deschamps,* "Ultrasonic transient bounded-beam propagation in solid cylinder waveguide embedded in solid medium," J. Acoust. Soc. Am, 121, 1924-1934, 2007.