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Laser Cladding of Ni-Based Powders on S355MC High-Strength Steel Substrate

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Abstract
Laser cladding is a technology in the field of surface engineering. Its characteristics, like versatility, high density of the energy, the various possibilities in selection of the laser beam led to metallic coatings with high quality. This quality however is dependent on the laser cladding equipment, materials and process parameters. The research work aims to investigate the geometrical characteristics of the laser cladding coatings and the behavior regarding bonding with the substrate of four different Ni-based powders on the same base material, S355MC. The S355MC is chosen because of its versatility and high usage in industrial fields. The four Ni-based powders are Metco 12C, Metco 14E, Metco 16CNS and Metcoclad 718. The experimental set-up was formed from a Trumpf TruPulse 556 milliseconds pulsed laser and Precitec WC50 as cladding module.

Keywords
laser cladding, Ni-based powder, S355MC, pulsed laser

1. Introduction

Over the last years, laser cladding has become an important technology in creating new surfaces, repairing the worn ones or prototyping in domains that requires high precision processes and high quality products. This process is an interdisciplinary technique that uses laser technology, CAD/CAM technology, robotics, sensors and powder metallurgy. The laser cladding uses a laser as a thermal source to melt and bond the filler material – a powder – to create a new surface [1, 2].

The filler material is generally a powder and may have similar properties to the base material – for example in reconditioning tasks – or may have dissimilar properties to the base material – for example in creating new surfaces. The deposition powder could be found in different metallic compositions – ferrous and non-ferrous [3].

There can be found in literature many names for this process – laser cladding – due to its various applicability. For example, this process in the coating domain is named “laser coating” [4, 5]. In the rapid prototyping field or applications that uses multi-layer manufacturing, this technology can be found under the name “selective laser sintering of metals” (SLSM) – [6, 7] or “direct metal laser sintering” [8].

Laser cladding has better quality over the arc welding coating process or plasma spraying process. The laser technique offers a better coating with lower dilution, lower dimensional errors and an overall better quality.

This technology offers many advantages in rapid prototyping technique as well. Rapid prototyping may be utilized to create a workpiece in a multi-layer fashion, which leads to unique features, such as a homogenous structure and overall better mechanical properties. [8].

In general, the laser cladding process is used for dissimilar metals (different base material and filler material) to modify the main characteristics of the workpiece, such as wear resistance, corrosion resistance and abrasions. In this process, there are two main parts: melt pool formation and blending by moving the laser and providing the filler material to the base material.

The melting pool and blending part of the process involves two parameters that need to be synchronized: the controlled temperature input by the laser to have a good mixture between the filler material and the base material and the temperature cycle to have a good control over the laser energy and an equal distribution of the temperature in the base material. The second part of the laser cladding is regarding the chosen method for providing the clad material to the substrate. The state of the art of this process specifies two ways to provide the powder to the base material: two-step process and one step process. [3]

In the two-step process, the first step represents the preplacing the clad material over the substrate surface, while the second step represents the actual melting the clad material and the base material surface in order to create a new layer. The filler material can be found in various forms: powder, paste, wire, foil, etc. The most utilized form in the two-step laser cladding process is the powdered filler material [9]. Powders are most commonly used in a slurry form, made of water, alcohol and powder. The aim of this mixture is to ensure good bonding with the base material and also to have a good amount of clad material on the substrate surface. It also protects the particles from the inert gas flow over the pre-placed powder in the second step of the two-step laser cladding. The water and the alcohol will be evaporated during the laser cladding.

Powell [11] explained that laser irradiation heats up the particles of the filler material – powder, but the limited interparticle contact does not allow the heat conduction. Following that, the particles that are irradiated melt and, in this state, now they can conduct the heat to the particles located next to them. Henceforth, this enables the propagation of the molten front through the insulating powder layer. Once the melted pool is wetting the base material, the chilling effect of the base material results in the reversal in the propagation of the molten front. Hence, the solidification starts but the melt-liquid interface is not going through the body of the base material as long as there is no extra interaction time or laser power. The energy delivered might be sufficient to shift the melt-solid interface downwards through the deposited layer and even across into the body of the base material if there is a continuous laser source which irradiates the melt surface. The depth obtained at the end of this process is representative of the dilution of the filler material. The providing of the exact amount of power and/or time to create a well fusion bond and a proper dilution is quite challenging. This technology ensures a high material efficiency, but it comes with disadvantages such as more requirements from the energy point of view than the purged powder technology. As a result of the comparison between pros and cons, the one-step laser cladding process is commonly preferred.

In this study, the one-step laser cladding process was used to carry the experimental tests. One step laser cladding represents a technique in which the filler material is fed to the melt pool made by the laser. The movement and the creation of the new surface are carried out either by the laser source and the filler material or by the movement of the base material. The complex geometry or the large areas of the workpieces can be carried out by overlapping beads. The filler material can be found in the form of a powder, wire or strip. Nickel based powders are the most used filler material for enhancing or reconditioning steel surfaces. Powder feeding laser cladding is the most used technique due to the various possibilities regarding the filler material – many materials and alloys can be found in the powder form. The good interaction between the filler material and the laser beam is also a valid argument for choosing this method. The simplest experimental set-up of the one-step laser cladding process has three essential components: the laser source, the robotic arm and the powder feeder system. The laser system is responsible for supplying the amount of energy needed for the process through a laser beam. The most common laser beams have linear, rectangular or circular beams. The linear and the rectangular beams have a uniform intensity, while the intensity of the circular ones depends on the radial distance. The shape of the beam is modeled by the optic system of the focusing mirror or lens and the spot size can be modeled by modifying the working distance between the focusing device and the base material surface. In general, the working surface is perpendicular to the laser beam. The powder feeder needs to be strong enough to deliver the right amount of filler material to the melt pool. The filler material can be delivered by a gas flow, which is commonly used due to its versatility regarding the working position and the anti-corrosion effect, or by gravitation. The laser beam irradiates the base material surface and creates a melt pool. Afterwards, powder is purged into the interaction area, is wetted by the melt pool and starts to melt as well. The delivery system – laser-powder – continues its way and the melt pool starts the solidification and following the sharpest thermal gradient, the deposition begins its forming.

The efficiency of catching powder particles is very dependent on the formation of the melt pool, which permits the catchment of the sprayed powder particles. The main disadvantage of this technique is the material efficiency, which stays between 40% and 80%. The characteristic element for the one-step process is the powder feeding system: off-axial and coaxial. The coaxial nozzle provides poorer catchment efficiency than the off-axial one. In the coaxial laser cladding process, the filler material is sprayed by a cladding module in shape of a cone surrounding the laser beam. This set-up provides the freedom of choosing the deposition direction. More than that, the interaction time between the laser beam and the powder is quite long which results in a preheating of the filler material particles while travelling to the interest area done in a more efficient way. Hence, it is expected that the efficiency of energy to be higher in this technique because of the multiple reflections that appear in the powder fog and longer interaction times [10].

The present paper aims to provide a better understanding of the coaxial laser cladding process, and the compatibility of the Ni based powders with the carbon steel substrate. This study, by using of a pulsed laser and by the selecting various filler materials will create a starting point in future research based on the interaction between these powders with carbon steel base materials.

2. Materials and Methods

2.1. Materials

The base material is a S355MC carbon steel. The S355MC is a high-strength low-alloy steel used in automotive industry for manufacturing of complex parts

The filler materials utilized in this study are four Ni-based powders from Oerlikon: Metco 12C powder, Metco 14E powder, Metco 16CNS powder and Metcoclad 718 powder. All the powders are self-fluxing and differ in their alloying compositions. These differences enable them to improve the mechanical properties of surfaces after cladding. The morphology of the powders is spheroidal in order to obtain a freely-flowing material for the laser cladding process.

The chemical composition of the powders is shown in the Table 1-4.

Table 1. Chemical composition of Metco 12C powder

C [%]	Si [%]	Fe [%]	B [%]	Cr [%]	Ni [%]
0.25	3.5	2.5	1.7	7.5	balance

Table 2. Chemical composition of Metco 14E powder

C [%]	Si [%]	Fe [%]	B [%]	Cr [%]	Ni [%]
0.5	3.7	2.75	2.2	11	balance

Table 3. Chemical composition of Metco 16CNS powder

C [%]	Si [%]	Fe [%]	B [%]	Cr [%]	Cu [%]	Mo [%]	Ni [%]
0.6	4.0	3.0	3.7	17	2.5	2.5	balance

Table 4. Chemical composition of Metcoclad 718 powder

C [%]	Nb + Ta [%]	Fe [%]	Ti [%]	Cr [%]	Al [%]	Mo [%]	Ni [%]
0.08	5	18	1	18	0.6	5	balance

2.2. Experimental set-up

The laser cladding process was carried out using a Nd:YAG pulsed “Trumpf TruPulse 556” with a peak power of 10 kW and a coaxial cladding module PRECITEC YC 50 with the focal length of 200 mm. The filler material was provided into the melt pool by an AT-1200HPHV Termach feeding system using inert gas – Argon – for transport and also for shielding. The filler material was provided into the melt pool through the four sockets of the nozzle and distributed evenly around the laser beam. The experimental set-up is presented in figure 1. The cladded layers with the four powders have been fabricated using optimized parameters from our previous study [12] and according to table 5.

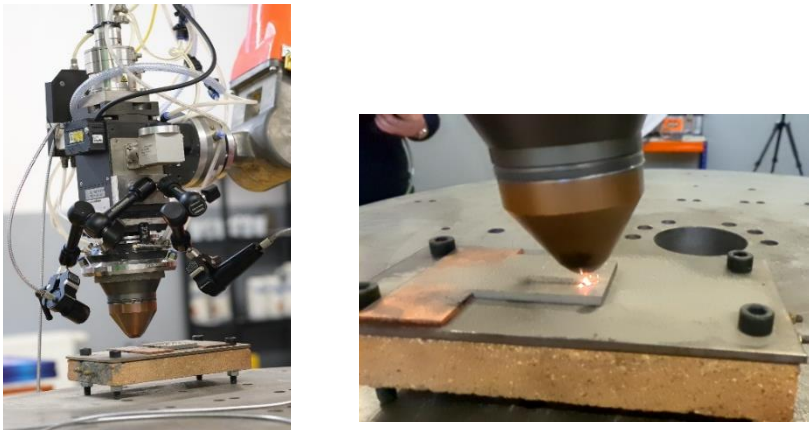


Fig. 1. Laser cladding experimental setup used for fabrication of samples 1 to 4

Table 5. Laser cladding process parameters and experimental set-up

Parameters	Sample 1 Metco 12c	Sample 2 Metco 14E	Sample 3 Metco 16CNS	Sample 4 Metco 718
Laser power [w]	1800	1800	1800	1800
Pulse Duration [Ms]	1.8	1.8	1.8	1.8
petition Rate [Hz]	60	60	60	60
Speed [cm/min]	30	30	30	30
Powder quantity [g/min]	5	5	5	5
Overlapping	45	45	45	45
Clad high [µm]	676.49	1059.18	948.86	1016.85

2.3. Methods

The macro images of the probes were taken by using LEICA EZ4 stereo microscope. The geometrical characteristics of the deposition and microstructures were inspected by using an optical microscope, a LEICA DML inverted microscope. The microhardness Vickers was acquired by using a INNOVATEST Falcon 600G2 automated hardness testing system with 200 gf and a dwell time of 10 seconds.

3. Results and Discussion

The samples have been prepared by cutting and sequential grinding and polishing. The cross section of the cladded layer is presented in figure 2. Defect free clads have been obtained using the optimized parameters.

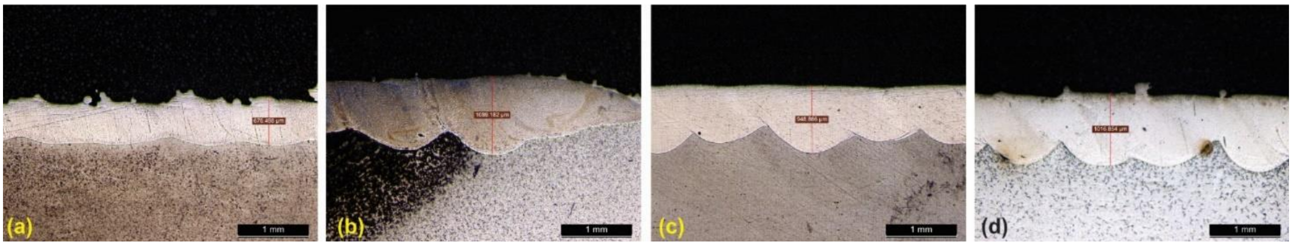


Fig. 2. Cross section appearance of the samples 1 to 4 at magnification 25x
a) deposition with Metco 12C, b) deposition with Metco 14E, c) deposition with Metco 16CNS, d) deposition with Metcoclad 718

Analysis of the deposition thickness reveals a slight difference between the Metco 12C powder and the other samples. This variation is attributed to the higher nickel content in Sample 1 compared to Samples 2, 3, and 4. Despite this difference in thickness, the dilution across all four samples remains low, ranging from 23% to 38%.

Figure 3 shows the cross section of samples 1 to 4 at higher magnifications. In can be observed that there is a clear delimitation, a noninterference line between the cladded layer and the substrate. The microstructure is formed by dendrite with a coarse geometry near the boundary (fig. 3 f) with the substrate and more fine and uniform distribution in the upper part of the layer (fig. 3 c).

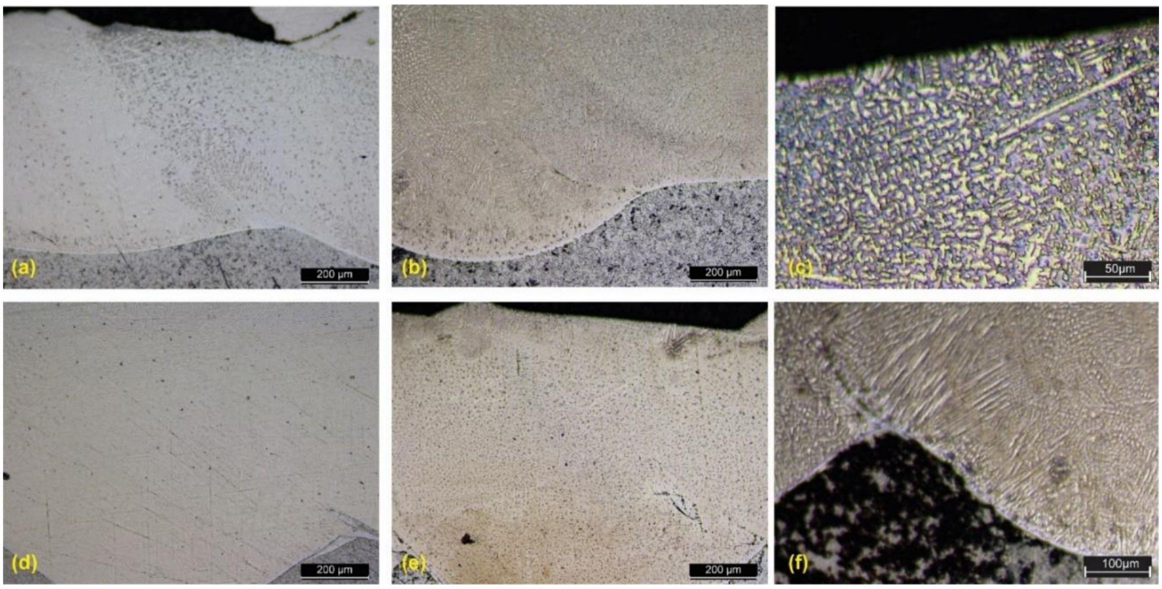


Fig. 3. Cross sectional views of the samples at magnification 100x
a) deposition with Metco 12C, b) deposition with Metco 14E, c) detail of the dendrite structure
d) deposition with Metco 16CNS, e) deposition with Metcoclad 718, f) detail of the boundary line

The cladded layers are characterized by improved hardness compared with the base material (166 HV02). The hardness profile of the four samples is presented in table 6 and 7. Measurements were realized both on the grinded top surface and across the cross-sections of each sample, as illustrated in Figure 4.

Table 6. Hardness values for the grinded top surface

	Indentation 1	Indentation 2	Indentation 3	Average
Sample 1	351.86 HV0.2	377.62 HV0.2	383.71 HV0.2	371.1 HV0.2
Sample 2	383.11 HV0.2	407.4 HV0.2	343.3 HV0.2	377.9 HV0.2
Sample 3	196.93 HV0.2	181.91 HV0.2	188.12 HV0.2	189.0 HV0.2
Sample 4	486.85 HV0.2	478.03 HV0.2	540.86 HV0.2	501.9 HV0.2

Table 7. Hardness values for cross section

	Upper zone	Center zone	Interface with the substrate
Sample 1	468.66 HV0.2	423.22 HV0.2	280.24 HV0.2
Sample 2	478.37 HV0.2	430.57 HV0.2	359.56 HV0.2
Sample 3	219.13 HV0.2	188.14 HV0.2	183.96 HV0.2
Sample 4	414.28 HV0.2	486.36 HV0.2	409.22 HV0.2

The hardness of the grinded surface of the cladded samples is presented in Table 6. A mean value obtained from three indentations was considered representative of the hardness characteristics for samples 1 to 4. The results indicate variations in hardness, primarily influenced by the composition of the powders used.

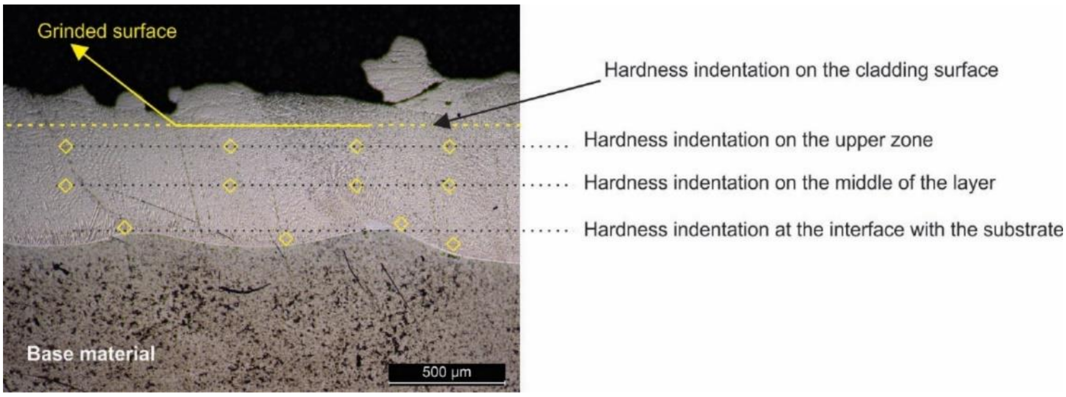


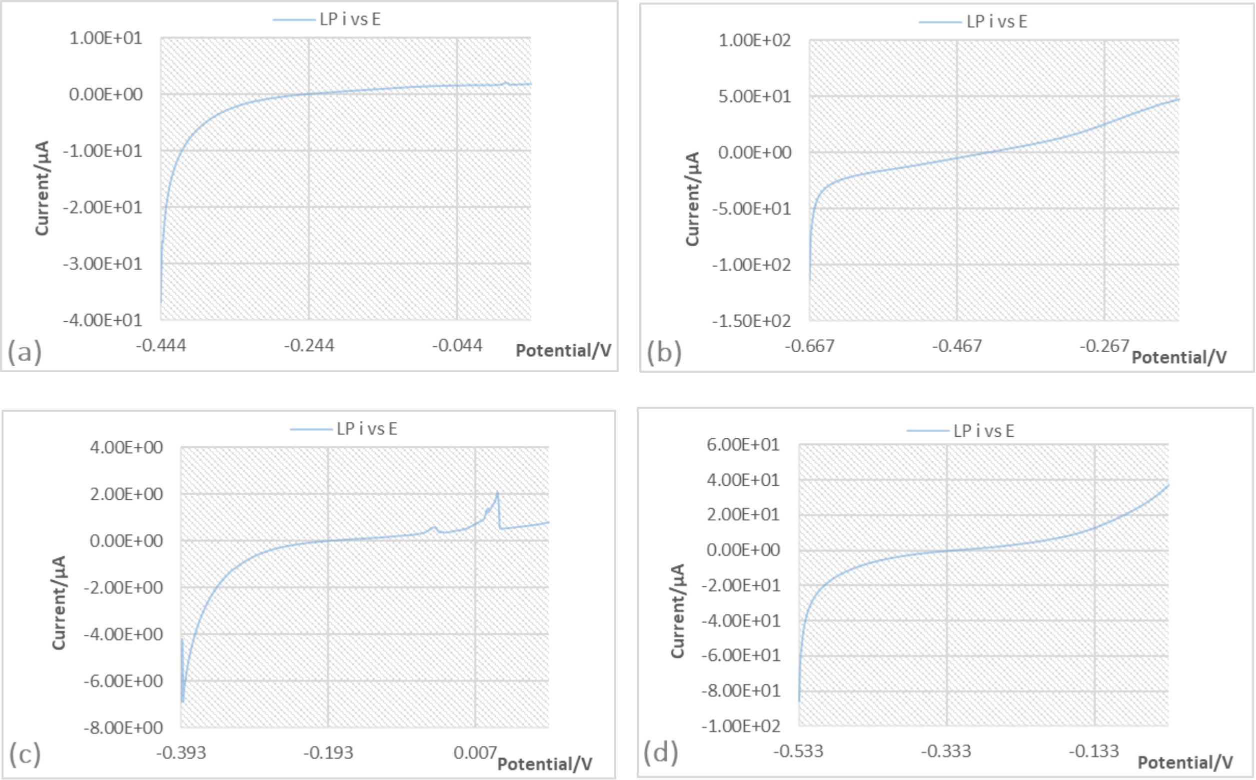
Fig. 4. Hardness indentation map

Sample 3 exhibits lower hardness values both at the surface and across the cross-section of the cladded layer. The identical process parameters significantly influenced the outcomes due to the differing chemical compositions of the powders. Variations in composition affected the absorption and reflection of laser radiation, leading to differences in the cladding process and resulting characteristics.

Table 7 illustrates the relationship between hardness and dilution phenomena. The hardness values can be used as indicators of elements migration, with iron migrating into the cladded material. This migration is evident from the comparison with the base material (S355MC), which has a hardness of 166 HV 0.2.

The corrosion resistance of the cladded samples was realized by electro-corrosion testing using the potentiodynamic polarization curves as depicted in Figure 5. The polarization curves reveal critical parameters such as corrosion potential, corrosion current density, and passivation behavior, which can provide details about the electrochemical behavior of the cladded layers.

The differences in corrosion resistance among the samples arise from the specific powder compositions.



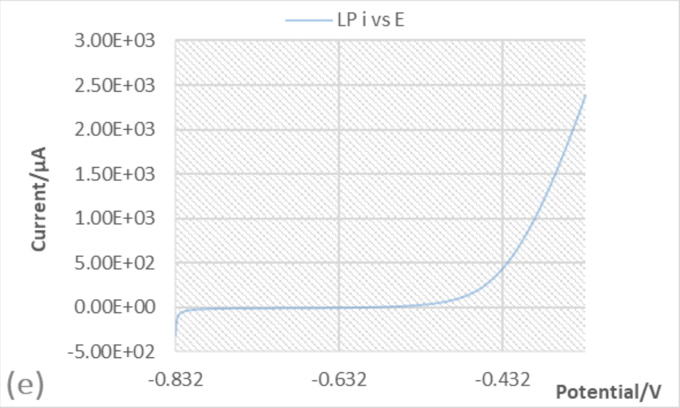


Fig. 5. Corrosion resistance of the cladded layers and base material
(a) polarization curve of sample 1; (b) polarization curve of sample 2; (c) polarization curve of sample 3; (d) polarization curve of sample 4; (e) polarization curve of the base material

Variations in alloying elements, particularly nickel and chromium content, influence the protective oxide layer formation and overall resistance to electrochemical degradation. Higher nickel and chromium levels enhance corrosion resistance, distinguishing the Metcoclad 718 (sample 4) from the other cladded samples and from the base material.

The base material, S355MC steel, does not have sufficient alloying elements such as nickel and chromium, resulting in a higher corrosion current density and lower resistance to electrochemical attack. This shows the significant role of the cladded layer in enhancing the material's performance in corrosive environments.

These results highlight the importance of alloy composition and microstructural characteristics in determining corrosion resistance.

4. Conclusions

Ni-based cladded layers were successfully fabricated using the four different commercial powders under optimized parameters, showing defect-free clads with consistent geometric appearance. The microstructure of the claddings is characterized by dendritic formations oriented towards the surface. Hardness measurements, taken from both the surface and cross-section, confirm the migration of iron into the cladded layers. It was determined that while Metco 16CNS demonstrated the lowest hardness, it exhibited the highest resistance to corrosion, indicating a favorable chemical behavior. The electrocorrosion testing highlighted the main role of alloying elements, such as nickel and chromium, in enhancing the corrosion resistance. Samples 3 and 4, respectively Metco 16CNS and Metcoclad 718, due to their compositions, formed more protective passive layers, making them ideal for applications requiring high corrosion resistance.

References

1. Toyserkani E., Khajepour A., Corbin S.F. (2004): *Laser cladding*. CRC Press, ISBN 978-0849321726
2. Stanciu E.M., Pascu A., Tierean M., Voiculescu I., Roata I.C., Croitoru C., Hulka I. (2016): *Dual coating laser cladding of NiCrBSi and Inconel 718*. Materials and Manufacturing Processes, eISSN 1532-2475, Vol. 31, is. 12, pp. 1556-1564, https://doi.org/10.1080/10426914.2015.1103866
3. Aggarwal K. (2014): *Investigation of Laser Clad Bead Geometry to Process Parameter Settings for Effective Parameter Selection, Simulation, and Optimization*. PhD thesis, University of Windsor, Ontario, Canada, https://scholar.uwindsor.ca/etd/5223
4. Ritter, U., Kahrmann, W., Kiipfer, R., Glardont, R. (1992): *Laser coating proven in practice*. Surface Engineering, eISSN 1743-2944, Vol. 8, is. 4, pp. 272-274, https://doi.org/10.1179/sur.1992.8.4.272
5. Jianglong L., Peidao D., Gongqi S. (1994): *Scanning electron microscopy study of laser coating microscopy*. Materials Characterization, eISSN 1873-4189, Vol. 33, is. 4, pp. 387-391, https://doi.org/10.1016/1044-5803(94)90143-0

6. Das S. (2003): *Physical aspects of process control in selective laser sintering of metals*. Advanced Engineering Materials, ISSN 1527-2648, Vol. 5, is. 10, pp. 701-711, https://doi.org./10.1002/adem.200310099
7. Abe F., Osakada K., Shiomi M., Uematsu K., Matsumoto M. (2001): *The manufacturing of hard tools from metallic powders by selective laser melting*. Journal of Materials Processing Technology, eISSN 1873-4774, Vol. 111, is. 1-3, pp. 210-213, https://doi.org/10.1016/S0924-0136(01)00522-2
8. Tang Y., Loh H.T., Wong Y.S., Fuh J.Y.H., Lu L., Wang X. (2003): *Direct laser sintering of a copper-based alloy for creating three-dimensional metal parts*. Journal of Materials Processing Technology, ISSN 1873-4774, Vol. 140, is. 1-3, pp. 368-372, https://doi.org/10.1016/S0924-0136(03)00766-0
9. Hoadley A.F.A, Rappaz M. (1992): *A thermal model of laser cladding by powder injection*. Metallurgical Transactions B, eISSN 1543-1916, Vol. 23, p. 631-642, https://doi.org/10.1007/BF02649723
10. Zanzarin S. (2015): *Laser cladding with metallic powders*. PhD thesis, University of Trento, Italy, http://eprints-phd.biblio.unitn.it/1590/1/Simone_Zanzarin_PhD_Thesis.pdf
11. Powell J., Henry P.S., Steen W.M. (1988): *Laser cladding with preplaced powder: analysis of thermal cycling and dilution effects*. Surface Engineering, eISSN 1743-2944, Vol. 4, is. 2, pp. 141-149, https://doi.org/10.1179/sur.1988.4.2.141
12. Cuculea D.C., Ardelean G., Stanciu E.M., Roata I. Pascu A. (2021): *Dilution in laser cladding with Ni-based powders*. Annals of Dunarea de Jos University of Galati, Fascicle XII Welding Equipment and Technology, eISSN 2668-6163, Vol. 32, pp. 56-60, https://doi.org/10.35219/awet.2021.07