Characterization and evaluation of laser cladding deposited coatings

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Abstract: *The paper contains recent work of the authors regarding the quality of layers deposited with the laser cladding technique. In the field of additive manufacturing, directed energy deposition (DED) in laser cladding presents both opportunities and challenges, especially in adapting to complex geometries while maintaining consistent material properties. Traditional laser cladding systems operate with fixed parameters, making it hard to balance precision and deposition efficiency. Smaller laser spot sizes offer high accuracy but lower deposition rates, while larger spots enable faster cladding at the expense of fine detail. This paper investigates an approach to adjusting parameters like laser power to achieve uniform material characteristics in 316L stainless steel claddings on 304 stainless steel substrates. The deposition parameters were adapted to the type of the materials that were used. Custom parameters are necessary in order for both the substrate and the alloy deposited, including laser power, laser spot size, advance speed, and degree of overlap between deposited layers.*

Key Words: *laser cladding technique, direct energy deposition, additive manufacturing, coating quality, optimum deposition parameters*

1. INTRODUCTION

In recent years, technological advances, together with the increasing demand for cost reduction and environmentally sustainable solutions, have driven the development and adoption of faster manufacturing technologies characterized by reduced energy and raw material consumption [1]–[6]. Among these technologies, laser cladding has gained significant attention as a deposition technique due to the multiple advantages it offers.

Laser cladding is a deposition method that has gained popularity in recent years due to the advantages it offers. A high-power laser beam is used as a heat source to melt a powder mixture fed directly into the deposition nozzle, and during the deposition, a partial melting of the substrate occurs to form a coating zone with minimal dilution at the interface, this improves the wear, corrosion and oxidation resistance of the support material [6]-[9].

In the laser cladding process, coating materials is in powder or wire form are melted using a high-power laser and subsequently deposited onto the substrate surface, resulting in the development of the deposited surface with low dilution rate at the interface which has minimal impact on the structure of the support material.

This process helps create protective coatings for better functionality and restore worn surfaces, which is why laser cladding has gained popularity in the aerospace, automotive, and medical industries due to several advantages. Among these advantages, the most important is that it helps extend the life of equipment, especially those that are worn, exposed to impact, and operating in a corrosive environment [1] – [7].

2. MATERIALS AND METHODS

The substrate material used in this study was AISI 304 stainless steel, widely employed in industrial applications due to its good corrosion resistance in atmospheric and moderately aggressive environments. Nevertheless, this alloy is known to be susceptible to localized corrosion phenomena, such as pitting and crevice corrosion, particularly in chloride-containing environments.

To improve the surface performance, the deposited material consisted of AISI 316L stainless steel powder, which exhibits enhanced corrosion resistance owing to its higher molybdenum content and improved stability in aggressive media. The use of 316L stainless steel as a cladding material allows the development of a protective surface layer with superior corrosion behavior compared with the substrate material [7].

Laser cladding is an additive manufacturing process were a high-power laser melts a coating material, typically supplied as powder or wire, and deposits it onto a substrate surface. The process produces a metallurgically bonded layer with low dilution, improving surface properties such as wear resistance, corrosion resistance, and mechanical performance.

The experimental procedure included the preparation of the substrate surface prior to the deposition process.

In order to remove surface impurities and oxide layers, the stainless steel substrates were subjected to sandblasting using electrocorundum as the abrasive medium (figure 1). The properties and chemical composition of electrocorundum used for experimental research are shown in table 1.

Table 1 - Properties and chemical composition of Aluminum oxide (Electrocorundum)

Physical properties	*Chemical composition*
Color: gray / black	Al_2O_3 95.65%
Hardness: 9 Mohs	TiO_2 2.42%
Granulation: 0.300 – 0.250 mm	Fe_2O_3 0.12%
Granulation shape is sharp	$Si0_2$ 0.92%
Melting point: 1950°C	CaO 0.35%
Specific gravity:3,9 - 4,1 g/cm^3	MgO 0.22%

Figure 1. Sandblasting equipment

After cutting the support samples for the deposition to 30x100 mm dimension, the surface was sandblast and then the degreasing operation was performed to remove various fats and the remaining sand.

Subsequently, the sample was cleaned in an ultrasonic bath to eliminate residual particles and contaminants from the treated surfaces.

Figure 2. Ultrasonic bath for sample preparation

Degreasing of the stainless steel samples was done for 15 minutes in an ultrasonic bath without temperature using alcohol for cleaning.

Deposition by laser cladding method

The samples were deposited in a facility using German equipment, ORLAS CUBE from O.R. Lasertechnologie GmbH. The facility consists of a laser system and a handling system. The laser system includes the laser head in which the beam is generated, the processing head through which the laser beam is focused on the workpiece and the control unit, including the laser electronics.

The CUBE laser cladding equipment (fig.3) used for the deposition is part of the equipment's of the Materials and Tribology Department of INCAS Bucharest.

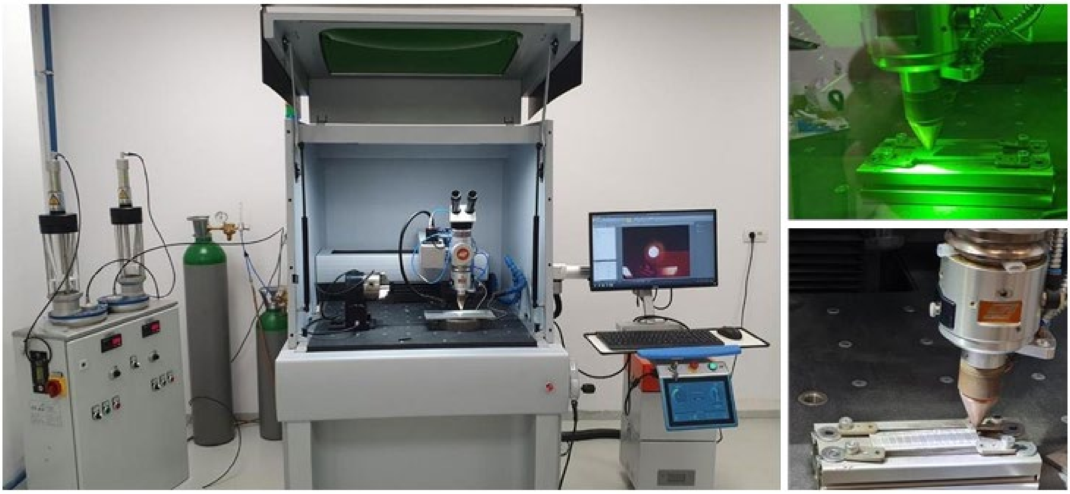

Figure 3. Laser cladding equipment

Deposition parameters

The cladding experiments are conducted using 316L stainless steel powder as the deposited material and 304 stainless steel sheets as the substrate.

The 316L powder used in this study is supplied by Oerlikon Metco under the full designation Metco Add 316L-D-106.

This austenitic stainless-steel powder is specifically designed for additive manufacturing technologies, including Laser Powder Bed Fusion (PBF-LB), Electron Beam Powder Bed Fusion (PBF-EB), and Directed Energy Deposition (DED).

Chemically, the powder consists primarily of iron, with 18% chromium, 12% nickel, and 2% molybdenum. It also contains less than 0.03% carbon, which prevents carbide formation and maintains ductility.

The powder is produced through inert gas atomization, resulting in a spheroidal particle shape, enhancing its flowability and packing density. The particle size distribution ranges from 45 µm to 106 µm, making it suitable for DED applications where controlled powder flow and consistent melt pool interaction are essential.

The apparent density exceeds 4 g/cm^3, with a solidus temperature of approximately 1390°C and a liquidus temperature of about 1448°C.

For the laser cladding process the scanning speed is fixed at 7 mm/s, a typical value in DED applications that balances heat input and track stability. To ensure consistent deposition quality, an argon shielding gas flow of 12 L/min is maintained to protect the melt pool from oxidation, while an argon carrier gas flow of 5 L/min is used to facilitate stable powder transport into the melt pool.

The only parameters adjusted during the study are laser power and spot size, which are varied to analyze their effect on track geometry, dilution, and overall deposition quality. In this case, laser spot is 0.2 and the laser power between 10% and 75%.

3. RESULTS AND DISCUSSIONS

The analysis of the track thickness and its structure was performed only on the central deposited track because at low power the deposition was not achieved, and at too high a laser power the deposition did not meet the quality requirements.

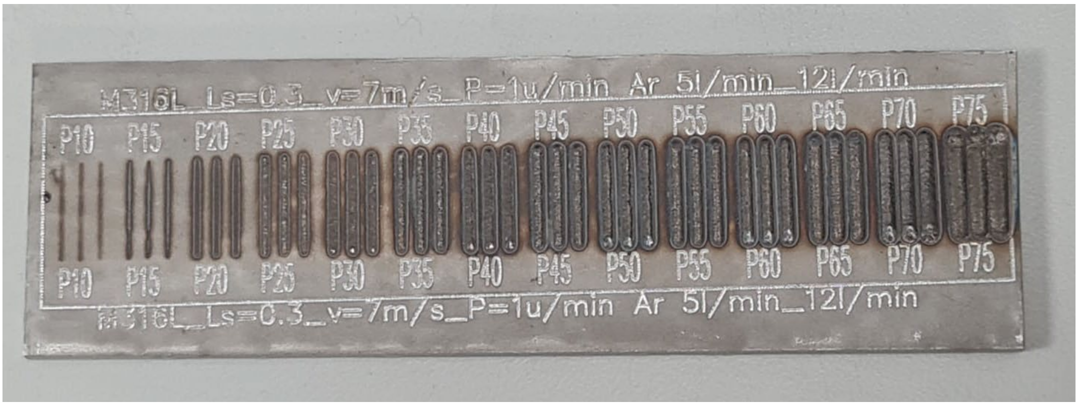

Figure 4. Macroscopic appearance of deposited layers with different laser powers

Microscopic analysis of the track and of the deposition track measurements

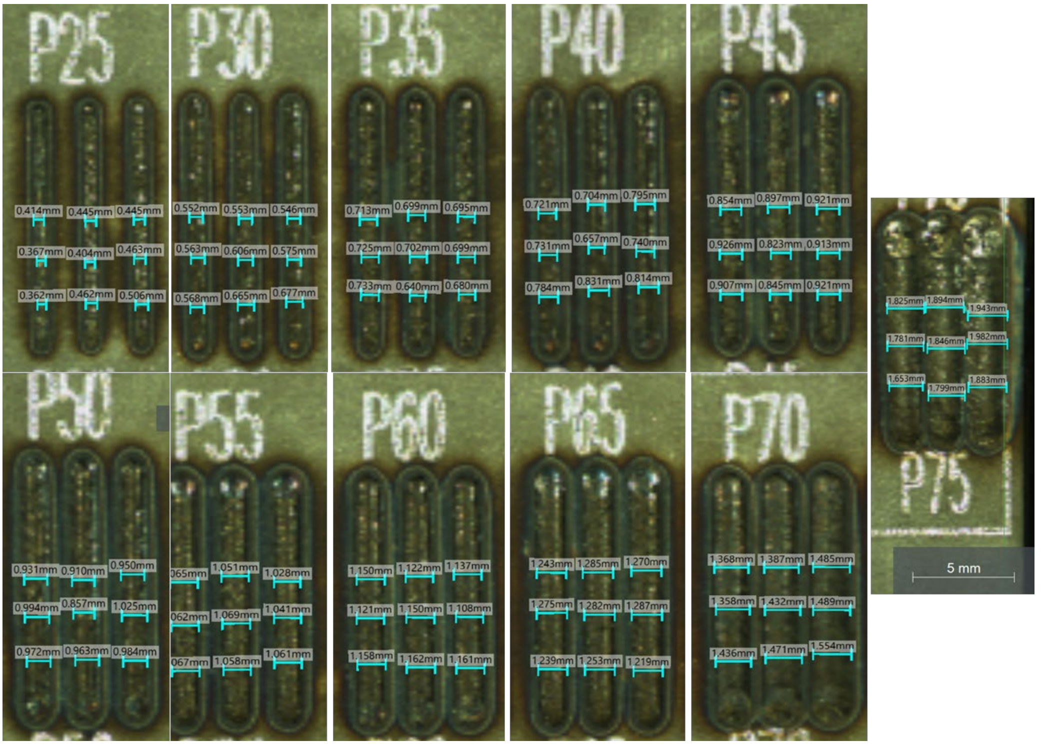

Figure 5. The measurements of the deposition tracks performed with laser power variations 25%, 30%, 35%, 40%,45%, 50%, 55%, 60%, 65%, 70% and 75%, spot size 0.2 mm, feed speed 7 mm/s

Table 2 - The measurements of the deposition tracks correlated with the laser power

Laser power [W]	**Laser power [%]**	**Support 304 / Deposited track SS 316L Ls=0,3mm**		
		Sample no.	Track width [mm]	Average value [mm]
150	25%	1	0.414	0.431
		2	0.445	
		3	0.445	
180	30%	1	0.552	0.589
		2	0.553	
		3	0.546	
210	35%	1	0.713	0.698
		2	0.699	
		3	0.695	
240	40%	1	0.721	0.753
		2	0.704	
		3	0.795	
270	45%	1	0.854	0.889
		2	0.897	
		3	0.921	
300	50%	1	0.931	0.954
		2	0.91	
		3	0.95	
330	55%	1	1.065	1.055
		2	1.051	
		3	1.028	
360	60%	1	1.15	1.141
		2	1.122	
		3	1.137	
390	65%	1	1.243	1.261
		2	1.285	
		3	1.27	
420	70%	1	1.368	1.442
		2	1.387	
		3	1.485	

450	75%	1	1.825	1.845
		2	1.894	
		3	1.943	

The average width value of the track increase exponentially with laser power.

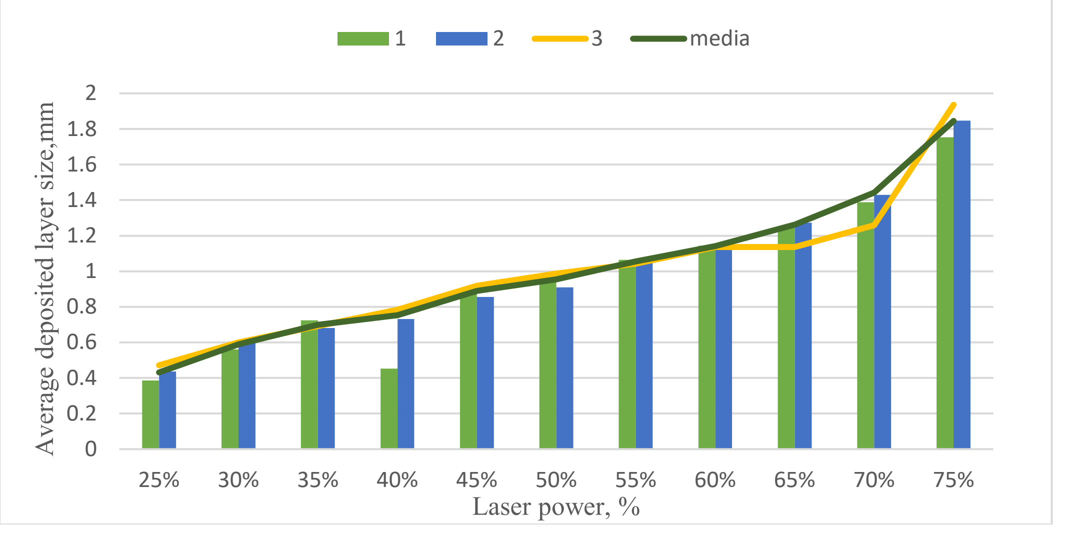

Figure 6. Variation of the deposited track width depending on the laser power

After obtaining the deposited tracks of the material with different parameters, cross-sections were cut to study the structural aspect of the deposits and their integrity.

Figure 7. Track microstructure, 40% laser power, 20x magnification

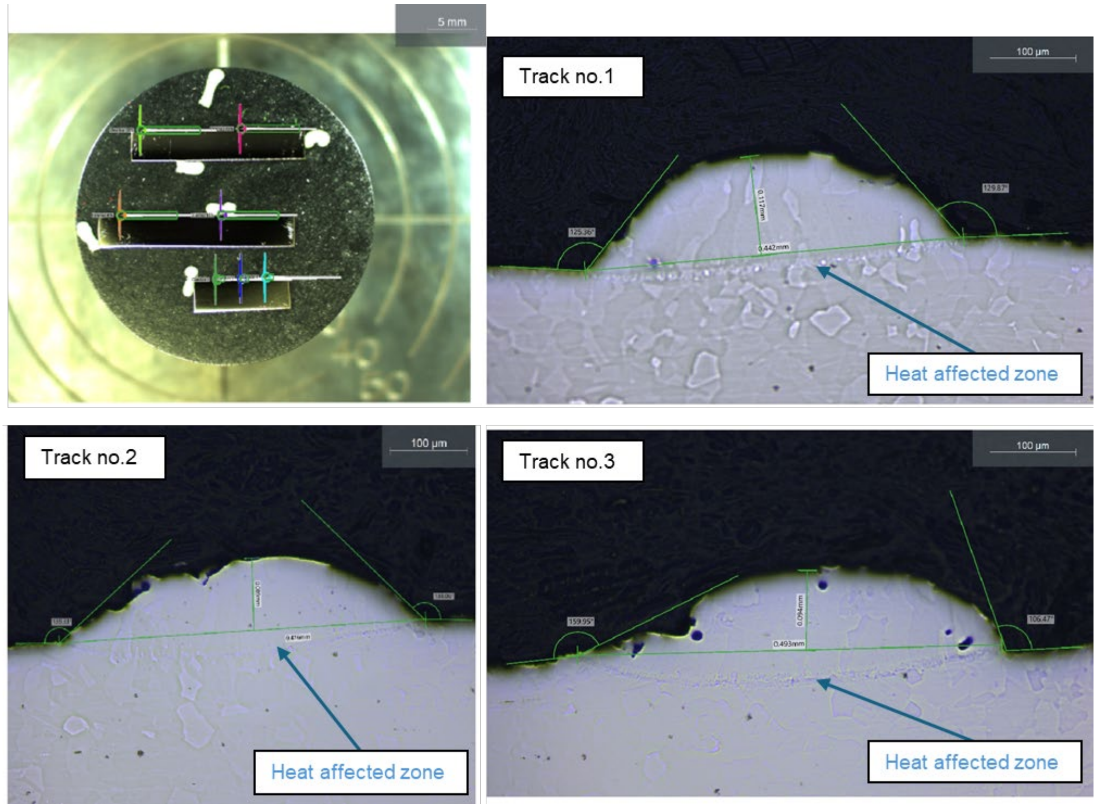

Figure 8. Microscopic analysis and deposition track measurement of 30% laser power deposition

Within the microscopic images, angle and cross-sectional dimensions measurements were also made for the 3 beads deposited at 30% laser power. The results are presented in the table below.

Table 3. Cross-section track measurements

	Trak 1	**Trak 2**	**Trak 3**
Width	0.493 mm	0.476 mm	0.442 mm
Length	0.094 mm	0.089 mm	0.117 mm
Angle	159.95 °	139.33 °	125.36 °
Angle	106.47 °	138.06 °	129.87 °

Optical microscopy observations revealed fine dendritic grain structures in all investigated samples, which can be attributed to the rapid solidification conditions characteristic of the laser deposition process.

High-resolution metallographic characterization was carried out on a set of specimens with single-layer deposits.

The samples were produced by varying the laser power parameters during deposition on an AISI 304 stainless steel substrate.

Hardness

The hardness measurements are made according to the ASTM E-384 standard. The microhardness testing in this study is conducted using the Vickers hardness (HV) method, specifically under the HV 0.02 protocol.

Table 4. Hardness points determinations

Test Point	Depth	Hardness (HV)
1	Deposition	217
2	Deposition	204
3	Deposition	227
4	Deposition	207
5	Interface	198
6	Substrate	254
7	Substrate	236
8	Substrate	229

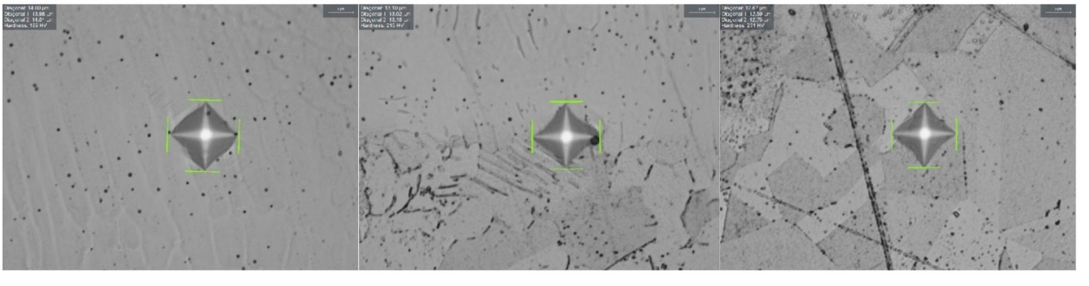

Figure 9. Vickers indentations left: cladding, middle: interphase and right: substrate, 30% laser power, magnification 20x

The work followed the influence of geometric and process parameters for 316L powder deposits on 304 stainless steel substrate by laser beam cladding method.

Following the research undertaken, the optimal parameters for uniform deposits were established, namely: laser spot: 0.2mm, feed rate: 7mm/s, argon flow rate: 5l/min.

Measurements were made for the cord width, observing higher average values at a laser power of 75% (450W).

The geometric parameters (deposition width and height) of the deposited layers indicated high values at a laser power of 300W, respectively for the width a value of 1845 µm.

Following the analysis of the deposited cords at different laser powers, 3 final variants were established for the deposition in order to optimize the process. The laser powers selected for these 3 depositions were: P30%, P35% and P40%.

4. CONCLUSIONS

The laser cladding method offers countless advantages over other traditional plating methods such as: the heat affected area is smaller, controlling the thickness and geometry of the deposited layer, the refined structure of the deposited layer which offers superior properties to the deposited layer, corrosion resistance, lightness and improved quality of the entire assembly.

Laser cladding allows for precise control over the coating, producing fine-grained structures with high hardness, increased spallation resistance, and enhanced oxidation and diffusion resistance compared to traditional methods like air plasma spraying.

An optimum parameter choosing increase the quality of the deposition and reduces the structure defects.

Laser cladding offers benefits like a fully dense, non-porous coating with very low dilution, which minimizes thermal distortion and results in a smaller heat-affected zone compared to air plasma spray.

This makes it ideal for creating high-quality, high-performance surfaces, repairing delicate components, and cladding traditionally “un-weldable” materials.

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