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INCONEL® 625 WIRE LASER CLADDING: PROCESS PARAMETRIZATION TO PRODUCE HIGH QUALITY COATINGS FOR METALWORKING INDUSTRY

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Abstract. *Laser cladding is a technique to produce high quality coatings that can be applied in several fields of industry. It makes possible the use of a vast variety of deposition materials, even ceramics, while still increasing productivity when related to other processes. The advantage of using wire as feedstock material instead of powder is the known higher productivity, the reduced material wastage and the possibility to have a cleaner process environment. Thus, the purpose of this study is to investigate the laser cladding process with a high power Ytterbium Fiber laser, while using Inconel® 625 wire as feedstock material. Through varying process parameters, as speed rate, focal adjustment and laser power output, the research aimed to obtain low dilution associated with high productivity results in order to validate the cladding process over a flat substrate. Scanning electron microscopy with energy dispersive X-ray spectroscopy, optical microscopy and microhardness techniques were used to characterize the material and were obtained as a result optimized productivity, low dilution and layer consistency. Wire laser cladding with Inconel® 625 demonstrated itself as a promising process to be applied in flat or, in coming works, curved surfaces.*

Key-words: Inconel® 625, laser cladding, corrosion protection, wire.

1. INTRODUCTION

There are few methods to prevent a material or structure for corrosion, e.g., metallic coatings, inorganic non-metallic coatings, organic non-metallic coatings (preventing inks and polymers), cathodic protection and anodic protection. Each of them can be used separately or combined, as metallic coating or non-metallic coatings with cathodic protection for pipe installation (Gentil, 1982). Inconel® is commonly used to prevent corrosion, applied as a coat on the surface of an steel, for exemple. Since Inconel® is a nickel-based alloy, it will protect the steel, because nickel can form a protective layer of oxides, due to the reaction with oxidants from the corrosive environment (Gentil, 1982; Al-Fadhli 2006; Lippold, 2011) Therefore, nickel is an cathodic coating when the substrate is carbon steel, and so its surface must be free of failures. Otherwise, in the presence of electrolytes, a galvanic cell will be formed and a quick corrosion of the coat material will happen (Gentil, 1982).

Laser cladding, or Laser Metal Deposition (LMD), is a coating technique for surface modification and it consists in melting the clad material by using a laser beam while depositing it over the substrate's surface. The aim is to improve part properties and thus, performance, e.g. corrosion resistance and wear, or to replace material that was degraded (Abioye, 2015; Heigel, 2016). Indeed, Inconel 625® was already a coating material in some researches of laser cladding, using fiber laser (Abioye, 2015; Abioye, 2013; Liu, 2014), diode lasers (Baldridge, 2013; Toyserkani, 2004) and ND:YAG laser (Kim, 2000).

There are several applications for LMD technology, specially in the fields off medicine, aerospace and automotive industries. Several researches were developed with different materials, as nickel-based alloys, cobalt-based alloys and titanium based-alloys, deposited on substrates as steel (e.g., unalloyed, alloyed, hardened, stainless steels), aluminum, cast irons and nickel or cobalt-alloys (Toyserkani, 2004). The three main methods to add the cladding material into the process are pre-placement of cladding material as powder on the substrate, inert gas propulsion of material as powder in to the molten pool and wire feed. And each of them is used for distinguished applications (Majumdar, 2013).

Wire material feeding has some advantages over powder as feed material, since the cladding process with wire generates less waste, reduces cost and contamination, has a higher material deposition efficiency, is adaptive with the cladding position, lower material cost and provides a cleaner process environment. However, when compared to the powder fed process, it can lead to lower surface quality, higher porosity, cracks, lower bonding strength and can have problems with drop transfer (Abioye, 2015; Heigel, 2016; Majumdar, 2013).

The basic setup of laser cladding processing with wire feed is shown in Figure 1. Secondary parameters – however still relevant – for the process with wire, as weld direction and speed, stick-out length, the angle between the wire torch and laser, distance laser/arc, focal length and focal plane position are depicted bellow (Frostevarg, 2014).

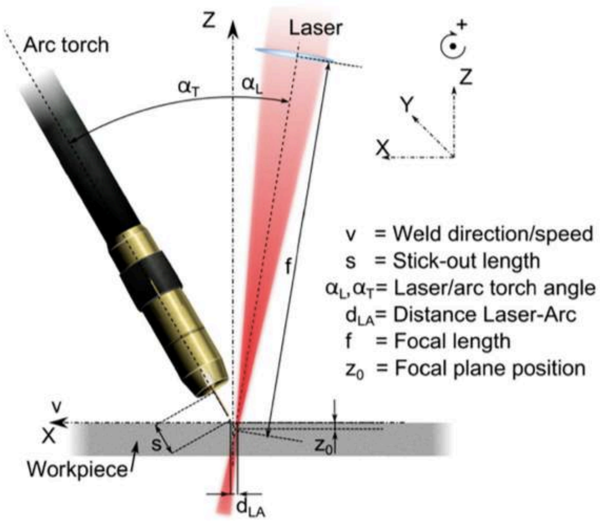

Figure 1. Scheme laser cladding with wire feed (Frostevarg, 2014).

Its main process parameters, such as laser power, feed rate and travel speed are the ones commonly modified, making possible to obtain distinct clad properties. In general, dilution is directly related to laser power and speed rate, when reducing the first and raising the second dilution will decrease (Abioye, 2015; Toyserkani, 2004).

Through the cross-sectional area is possible to analyze the morphology of the clad. And the morphology depends on the wetting angle and interfacial free energies (solid-liquid, solid-vapor and liquid-vapor interfacial energy), which will influence on the clad dilution ratio.When there is a high power output, there will be a high dilution and lower wetting angle, (Figure 2a) and the result of oxidation of the substrate can lead to poor wetting no dilution and no wetting between the clad and substrate (Figure 2c), both situation from Fig. 2a and 2c are not desirable. The ideal clad morphology is shown in Fig. 3b, with adequate dilution and wetting angle (Toyserkani, 2004).

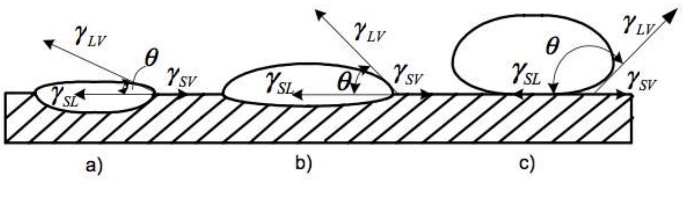

Figure 2. Morphology of the clad cross-sectional area (Toyserkani, 2004).

In this work, single beads of Inconel® 625 wire were studied under different process conditions. In addition, the microstructure of the clad and the substrate were investigated.

2. EXPERIMENTAL PROCEDURE

2.1 Materials

As cladding material, wire of Inconel® 625 was used, while sand blasted plates of ASTM A516 Gr.70 were chosen as substrate material. The typical composition of Inconel® 625 by specification of UNS N06625 and the substrate material composition is shown in Tab. 1.

Table 1. Chemical composition of Inconel® 625 and ASTM A516 - Gr.70.

	C %	Cr %	Si %	Ni % (min)	Mo %	Fe % (máx)	Nb+Ta %	Mn% (máx)	S% (máx)	P% (máx)
Inconel® 625	≤0.10	20-23	0.50	58	8-10	5	3.15-4.15	0.5	0.02	0.02
ASTM A516 - Gr. 70	0.27	-	0.13-0.45	-	-	Bal	-	0.85-1.2	0.02	0.02

2.1. Laser processing

For the experiments, a 10 kW fiber laser was used, manufactured by IPG Photonics (IPG - YLS 10000). The laser operates at 1060 nm wavelength and in continues mode, with 0.8 mm of beam diameter in focus. The laser head moves in Z axes while the specimen can move in X and Y axes. The source for the wire is a IMC Digiplus A7 MIG-welder, the wire feeding angle was 45˚, the wire diameter is 1.2 mm and the wire feed rate is 3.1 m/min. The setup of the experiment is shown in Fig. 3.

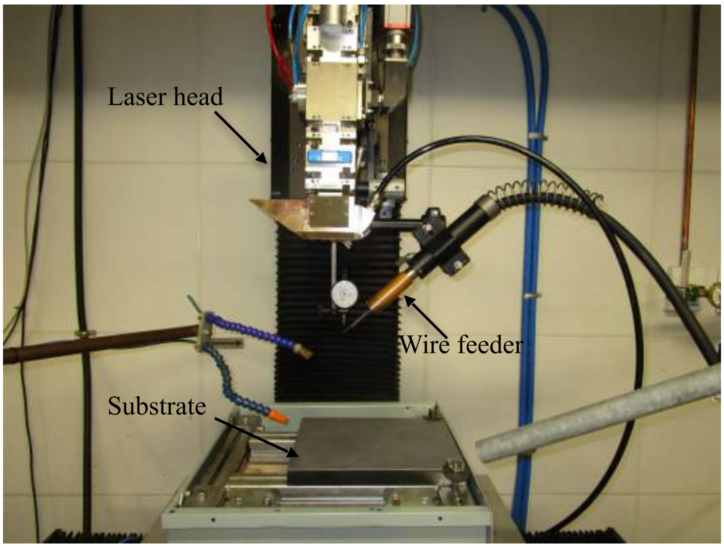

Figure 3. Experiment setup at Laboratório de Mecânica de Precisão (LMP).

Parameters analyzed were power output (0.5, 1, 1.5 and 2 kW), speed rate (1000, 2500 and 4000 mm/min) and distance to focus (15, 25 and 35 mm). In all the tests, argon was used as shielding gas (10 l/min), which protects the material from oxidation.

2.3. Analysis

To characterize the samples, scanning electron microscopy (Hitachi 3030), EDS, optical microscopy (Olympus BX60M) and microhardness techniques (Shimadzu HMV) were used. The hardness test was made by a Vickers hardness testing machine (0.5 HV) and four measurements were made in a time from the coating to the substrate. The measure I and II were made at the coated surface, III was made at the heated affected zone (HAZ) and IV was at the original substrate (Figure 4). Therefore, for a better data treatment, the measurement was repeated three times in the same sample, aiming an average value.

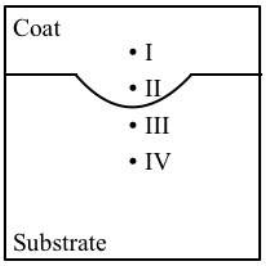

Figure 4. Scheme the positions of microhardness measurement points.

3. RESULTS AND DISCUSSION

All the clad tracks processed with dislocation of 15 mm from the laser focus are shown in Fig. 5, and from these clads is possible to note an increase of dilution with the increase of power output significantly. For the samples with 1000 mm/min of speed rate, the dilution increases from 25% (1.5 kW) to 47% (2.0 kW). Further on, the increase of speed rate decreased the wetting angle between the substrate and coating.

In relation to the increase on speed rate, there were a reduction of material deposition, leading to cases even without clad adhesion on substrate, for example, the sample with 1 kW and 4000 mm/min (Figure 5). For the tests with higher distance to focus, 35 mm, there were no adhesion for samples where it was used 2500 mm/min as speed rate. Two of three samples at 4000 mm/min with 25 mm did not adhere to the substrate.

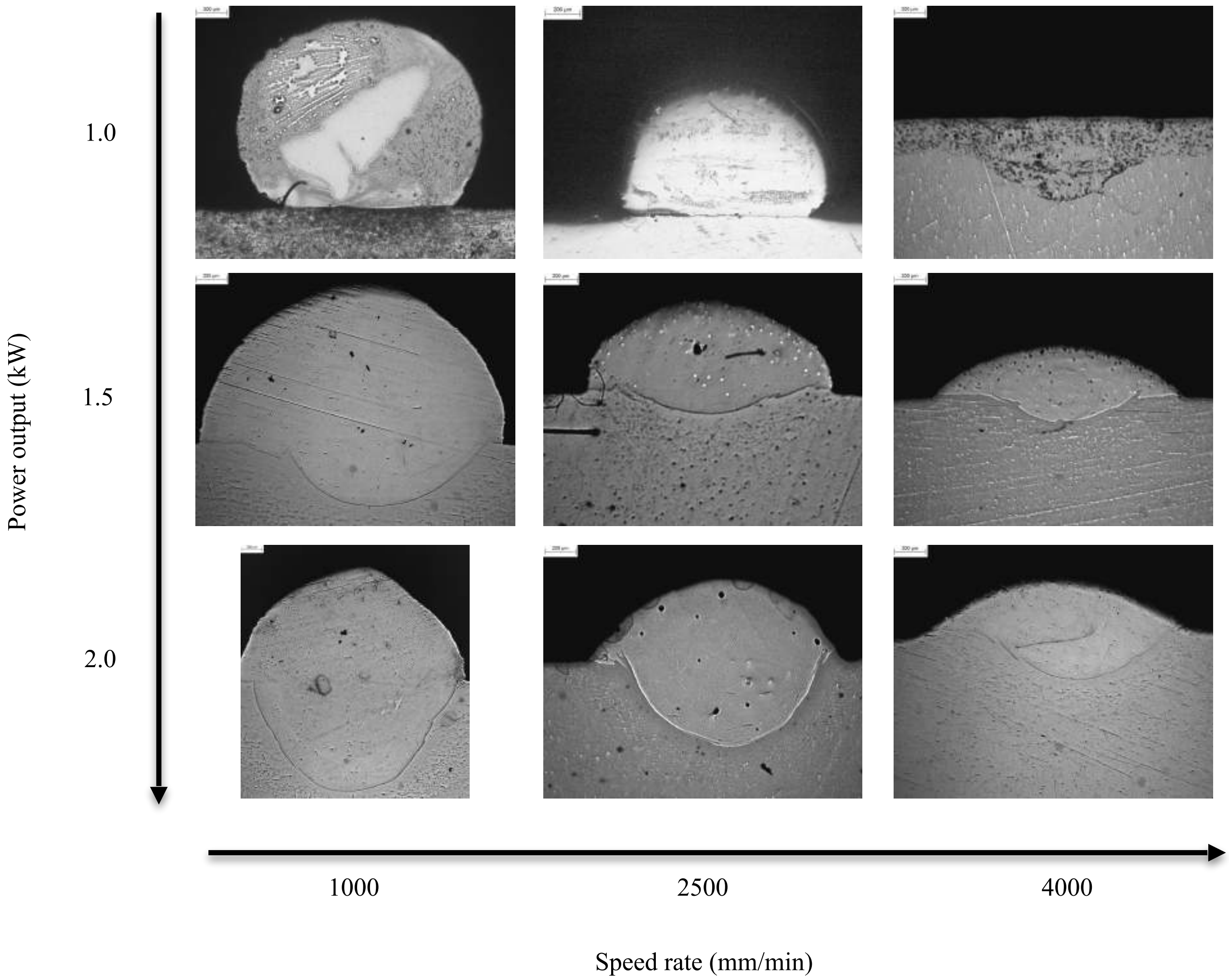

Figure 5. Micrographs single from clad lines.

Furthermore, regarding the distance to focus, was also possible to notice a linkage between the material deposition, dilution and wetting angle, the higher the distance to focus, the lower the layer thickness is; lower is the dilution and higher is the wetting between substrate and coating (Figure 6).

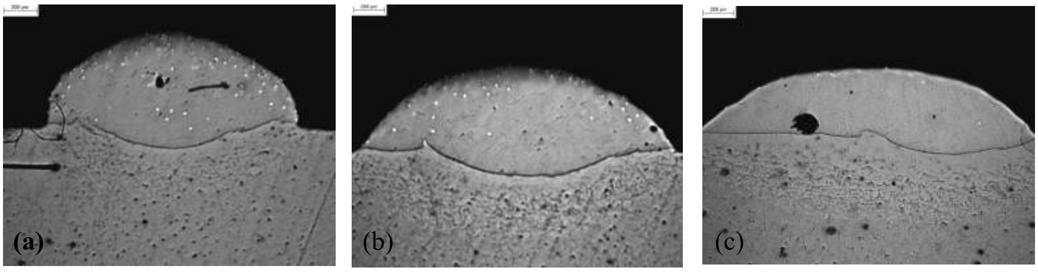

Figure 6. Parameters (a) 1.5 kW, 15 mm, 2500 mm/min; (b) 1.5 kW, 25 mm, 2500 mm/min; and (c) 1.5 kW, 35 mm, 2500 mm/min.

Based on dilution, productivity and absence of defects, such as porosity or lack of adhesion, three samples were selected to repeat the parameters doing overlap rate of 10%, 20% and 30%. Productivity is being here considered the area covered by time of processing. The chosen parameters to fulfill the purpose of high productivity, low dilution and low porosity were 1.5 kW, 35 mm, 1000 mm/min; 1.5 kW, 25 mm, 2500 mm/min; and 1.5 kW, 15 mm, 4000 mm/min.

Overlap rate of 10% generated for all parameters combination lack of fulfillment between the two clads, and this also happened for some samples of 20% (Figure 7.a). Besides, samples with 30% of overlapping had the most appearance of porosity (Figure 7.c).

Figure 7. Parameters (a) 1.5 kW, 35 mm, 1000 mm/min, 20%; (b) 1.5 kW, 25 mm, 2500 mm/min, 20%; and (c) 1.5 kW, 15 mm, 4000 mm/min, 30%.

The 1.5 kW, 25 mm, 2500 mm/min, 20% specimen was the one with less percentage of porosity and also did not presented severe defects (Figure 7.b). For the hardening studies, the three samples shown in Figure 7 were chosen, according to the scheme presented in Fig. 4.

Microhardness of sample 1.5 kW, 25 mm, 2500 mm/min, 20% and 1.5 kW, 15 mm, 4000 mm/min, 30% remains practically constant until the third measurement, which is in the heat affected zone. Probably in this region a grain refinement happened, and so, hardness is higher than the substrate hardness (around 160-170 HV). For the sample 1.5 kW, 35 mm, 1000 mm/min, 20%, there is a increase of the hardness in the third measurement, also can indicate grain refinement or even change of phase with a martensitic structure. Then there is a sharpe decline, with the values similar with the another conditions.

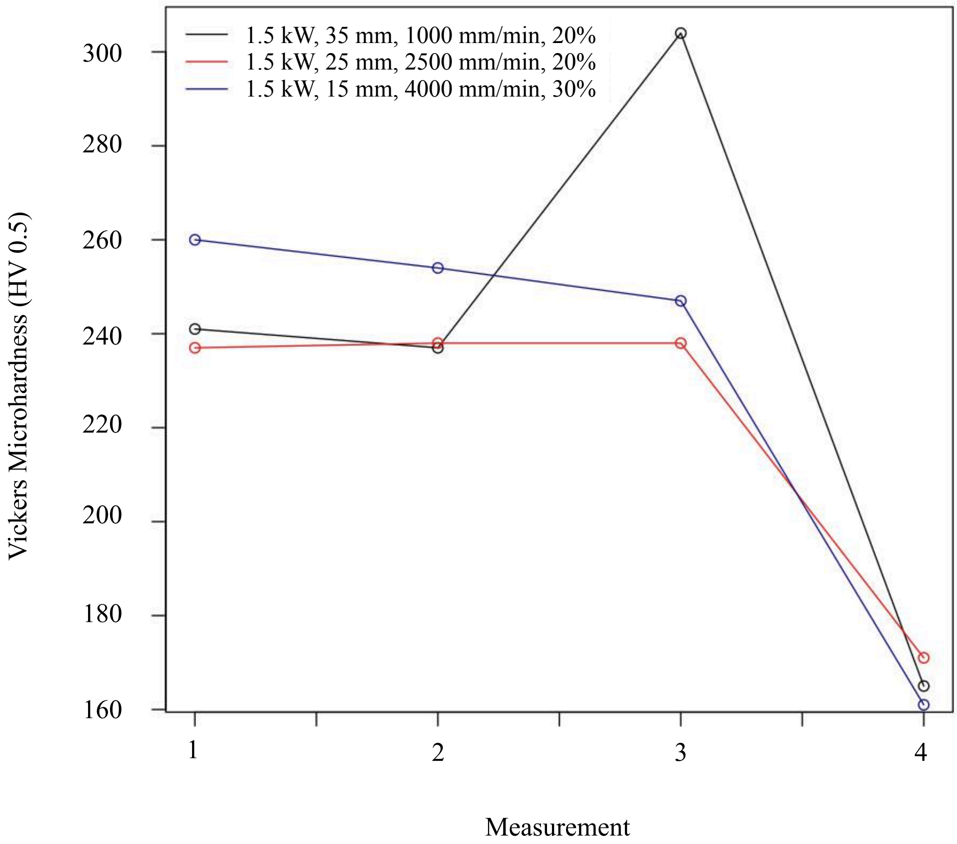

Figure 8. Microhardness (HV 0.5 for 10 seconds).

4. CONCLUSIONS

The results showed in this research are promising for implement the laser cladding process with Inconel® 625 in the industrial environment. Laser cladding with Inconel® 625 wire as feedstock material demonstrated itself as a productive tool with strong metallurgical bonding in the coat of surfaces with ASTM A516 – Gr. 70 as substrate.

Further, was possible to produce coating without porosity and dilution rate up to 5% and average around 20%, yet lower than conventional techniques for coating, as thermal spray. As expected, the productivity is higher, when compared with typical values for laser cladding with powder and it can still be improved if a wire preheating system was used.

5. ACKNOWLEDGMENTS

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