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Wire- and powder laser cladding of Inconel® 625

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ABSTRACT

Due to the material properties and process applicability, laser cladding of Inconel® 625 is ought to have applications in the aerospace and deep-sea pipeline coating. This study background refers to the second application; thus, only single clad layers are presented. The focus is the comparison of layers made with wire and powder feeding laser cladding strategies. Processes suitability regarding application will be pondered over, while characterizing Inconel® 625 depositions and considering process characteristics. In a first step, the analysis considers a comparison between both cladding methods, operating within assumptions and a similar range of main parameters. After inferring from these results, the achieved knowledge is used to adjust settings on the second step, where both processes are optimized individually. Clad quality is evaluated regarding to geometry through optical microscopy, dilution percentage and chemical composition in different positions in the clad are analysed by EDS and substrate-to-clad hardness is measured.

1. INTRODUCTION

According to various newspaper reports, pipeline protection becomes more and more important. Currently, many pipelines do not reach the end of their life time they were designed for. A lot of pipeline failures due to corrosion occurred, damaging environment, finances, but also human lives. It is expected, that similar problems will continue to happen [1]. To prevent an increasing trend of corrosion failures a lot of research is done in this field. Current pipeline corrosion prevention techniques can be divided into two procedures: coated layers and sacrificial anode protection [2]. This work refers to the first technique.

The Inconel® 625 is a Ni-based superalloy used in various fields of applications, such as the manufacturing of aerospace components or pipeline coatings. Laser cladding, the object of this study, is a process applied in both fields, as in additive manufacturing or repairing turbine parts or cladding a pipeline against corrosion and other erosive factors [3]. The present study compares Inconel® 625 single-layer depositions made by the processes of wire- and powder laser cladding and evaluates overall clad aspects.

The current research progress is presented. Continuous single step depositions of material over the substrate while irradiating the same spot with the laser beam are carried out. Powder and wire feeding are chosen because they are the commonly used and suitable for free form surfaces. Schematics of the wire- and powder fed processes are shown in Figure 1.

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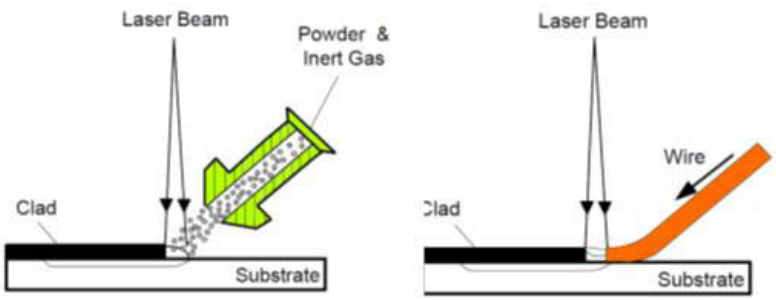

Figure 1: Powder and Wire fed depositing [5].

Both methods of material feeding strategies have advantages and disadvantages. The wire feeding process is more efficient, wasting less material and is independent from gravity when processing difficult geometries, but the powder-feeding process claims to show up better results and to be less sensitive [4][5].

The study's objective is to observe the general characteristics of both methods identifying the tendencies of the results.

2. EXPERIMENT

The experimentation with the two processing techniques – powder laser cladding and wire laser cladding – is divided into two steps, being compared one to the other. In the first step equivalent entrance parameters are used. Single clad lines were applied to define the range of parameters that result in the desired quality for surface coatings in step two.

The set-up of both processing techniques is very similar. The laser cladding research rig is based on a 3D NC Cartesian movement system. integrated with an IPG-YLS 10,000 W fiber laser, a gravity based GTV PF 2/1 LC powder feeding system with backpressure and a coaxial powder feeding nozzle from ILT FhG and a STA20-2 wire feeding system from IMC Soldagem, mounted at a 45° angle pointing into the center of the focus region of the laser beam.

In both material feeding processes Inconel® 625 is applied on ASTM A516 gr.70 steel plates, similar to ones used in the pipeline industry [6]. The diameter of the Inconel® 625 wire is 1.14 mm and the Inconel® 625 powder is sieved to a maximum particle size of 106 µm with a chemical composition showed in Table 1.

Table 1: Inconel® 625 Chemical Composition.
Source: Certificate of Analysis by Höganäs

Inconel® 625 - Chemical Composition						
	Mo	Fe	C	Cr	Si	Ni
W_t %	8.9	0.43	0	21.2	0.42	Bal
Min %	8.0	0	0	20.0	0.3	Bal
Max %	10.0	1.5	0.3	23.0	0.5	Bal

The two material feeding systems are shown in figure 2. For powder feeding the processing nozzle (Figure 2 – Left) combines the shielding gas, laser and powder supply in one coaxial nozzle. The wire feeding processing head separates the wire supply, laser power, cross jet and shielding gas (Figure 2 – Right).

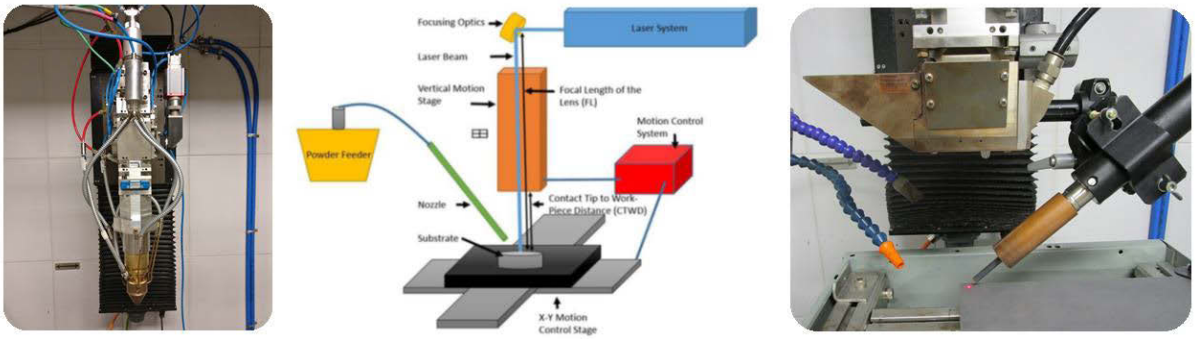

Figure 2: Laser cladding set up (left: powder feeding head; right: wire feeding head).

The first part of the experiment consists of cladding single lines which are performed with feeding rates of 16 g/min and 27 g/min. Within each single line, parameters such as laser power, cladding speed and focal distance are varied. The parameters listed in the table 2 are based on literature research [4][5]. With the results, the clad lines are classified according to the clad quality.

Table 2: Process Parameters (Line Tests).

Parameter	Laser Power (W)	Focus position Z (mm)	Cladding Speed (mm/min)
Value	500 - 2000	+15, +25, +35	500 - 4000

In the second step overlapping clads are performed, using the entrance parameters of the best single clad results, to produce coating surfaces with different overlapping ratios in a range of 10 % - 30% with the aim to provide a good match between productivity and quality.

For the characterization of the clads, especially concerning dilution, wetting angle, productivity, microhardness (Vickers) and chemical composition, scanning electron microscopy (Hitachi 3030), dispersive X-ray spectroscopy, optical microscopy (Olympus BX60M) and microhardness techniques (Shimadzu HMV) are applied.

3. RESULTS & DISCUSSION

The first experiments used a powder feeding rate of 20 g/min, which corresponds to the equivalent to 1.9 m/min of wire feeding. The first single clad lines produced with powder feeding process provided different characteristics, depending on the entrance parameters. Typical problems observed in both cladding techniques are shown in the figure 3, varying from extreme high dilution, too extreme low dilution with a big wetting angle or presenting pores.

Figure 3: Process characteristics, as high dilution (left), low dilution with a big wetting angle (middle) and presenting pores (right).

The best single clad lines were obtained with 20 g/min powder feeding at a focal distance of +15mm (above the surface of the plate) with a laser power of 500 W, a cladding speed of 1,000 mm/min (Figure 4), a laser power of 1,200 W and a cladding speed of 3,000 mm/min at +25 mm and a laser power of 1,000 W and a cladding speed of 1,000 mm/min at +35 mm.

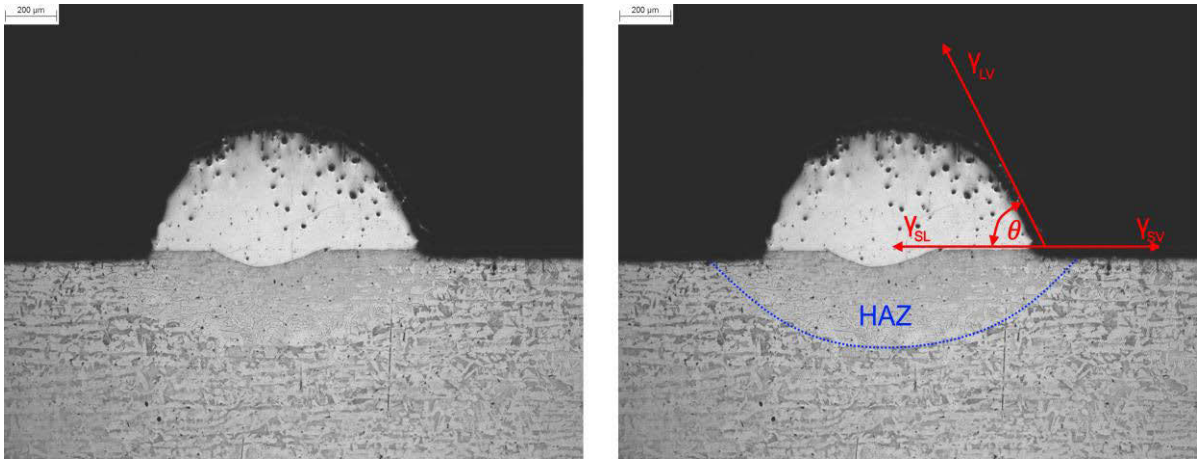

Figure 4:Single line clad performed with 20 g/min, 500 W laser power, 1000 mm/min feed rate and focus position of +15 mm (above the surface).

Figure 4 shows a powder feeding cladding result with low dilution, a symmetric heat affected zone (HAZ) and a wetting angle $\Theta < 90^{o}$.

The wire feeding process at the same material and energy supply provided mostly inconstant clad line results.

In the next step, the powder feeding rate is increased from 5 to 27 g/min (equalling 3.1 m/min at wire feeding). At this condition good clad line results with wire feeding process were obtained, Figure 5, using a laser power of 1,500 W at a focal distance of +15 mm, +25 mm and +35 mm and cladding speeds of 1,000 mm/min, 2,500 mm/min and 4,000 mm/min.

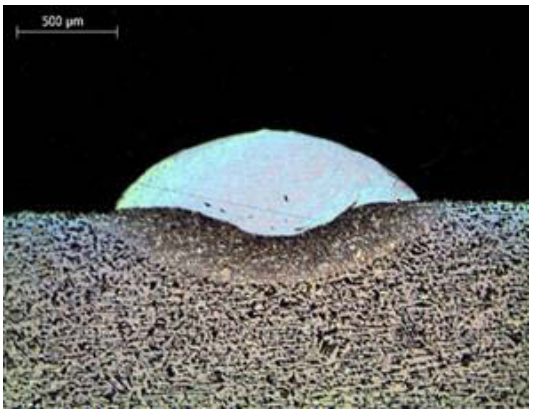

Figure 5: Single Clad Line obtained with 3.1 m/min wire feeding , a laser power of 1,500 W, the optical focus at +15 mm and a cladding speed of 4,000 mm/min .

Figure 5 represents a single clad line obtained with wire feeding, at a laser power of 1,500 W, a focal distance of 15 mm and a cladding speed of 4,000 mm/min in this example. Increasing the laser power up to 2,000 W leads to higher dilution, whereas decreasing the laser power to 1,000 W results in low wetting.

Evaluating the influence of the increase of the powder feeding rate, it was observed that the powder supply turned discontinuous. This was correlated to the shape of the used powder particles. The maximum feed rate of the powder feeding device is too high for the employed powder nozzle using the Inconel® 625 powder, so it got stuck and a constant powder flow could not be guaranteed.

Figure 6 shows that the powder consists of two different types of particles. There are round shaped ones and irregular shaped ones. It was assumed that the irregular shaped particles caused the inconstant powder flow when using higher feeding rates.

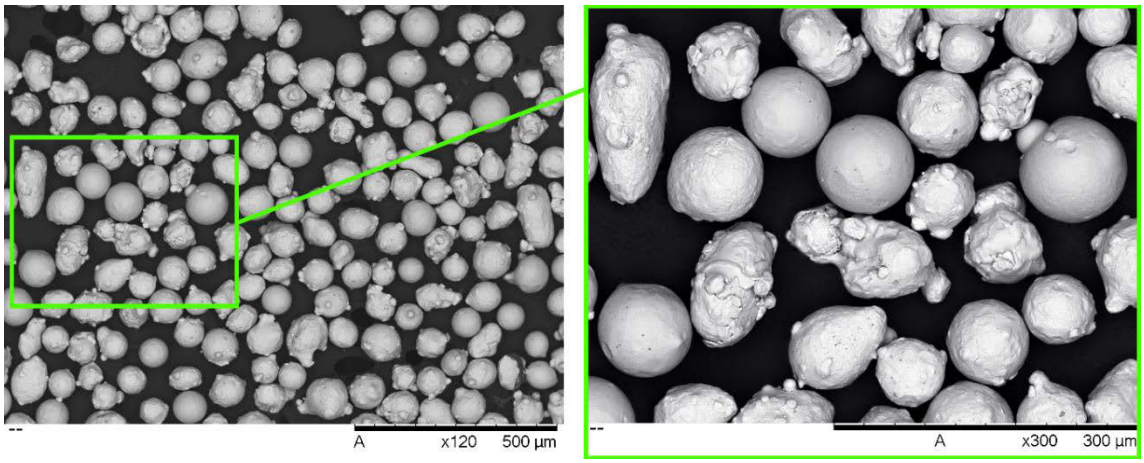

Figure 6: Powder Particle Shape Inconel® 625.

Based on the results obtained in the first experiments, parallel lines were applied to coat a surface with both material feeding techniques, the different focus position and laser powers to compare the coatings. The results while doing overlapping tests are pictured in the figures 7 and 8.

Figure 7 shows single clad lines with too high hatching distances. Figure 8 shows cladding results with an overlap ratio, but with pores in the clad line borders.

Figure 7: Cladded lines with to big hatching distance.

Figure 8: Overlapped cladding lines with pores.

An increase of the overlap ratio led to significant increase of the quality of the cladded surface. But an increase of the overlap ratio decreases the productivity of the process.

The best balance of quality and productivity in the wire feeding process was achieved by using a laser power of 1,500 W, a cladding speed of 4,000 mm/min and a focal distance of +15 mm and the feeding rate of 3.1 m/min, Figure 9.

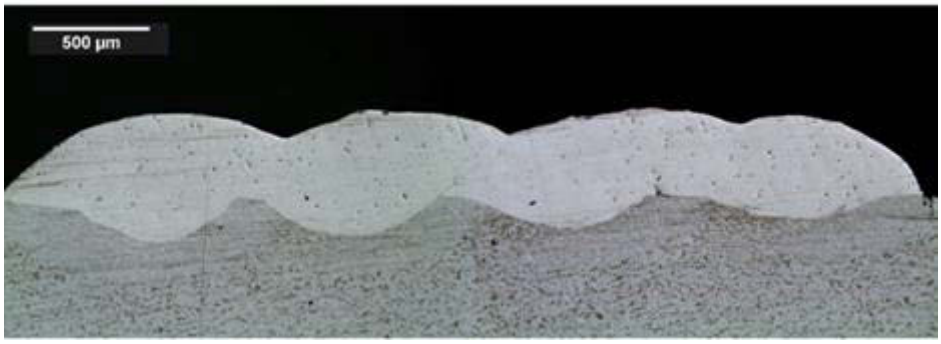

Figure 9: Cladded surface obtained with 3.1 m/min wire feeding 1,500 W laser power, focal distance of +15mm.

The best results of the of surface cladding with powder feeding was obtained using a powder feeding rate of 16 g/min, a laser power of 1,000 W, a focal distance of +35 mm and a cladding speed of 1,000 mm/min, Figure 10.

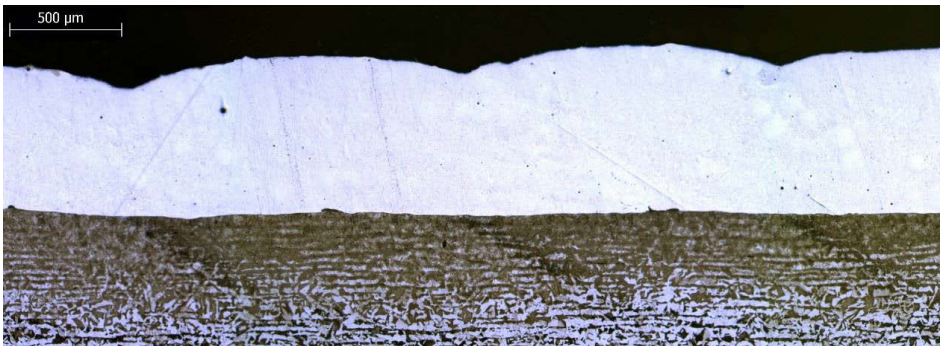

Figure 10: Cladded surface obtained with 16 g/min powder feeding, a laser power of 1,000 W, a focal distance of +35 mm and a cladding speed of 1,000 mm/min.

The Vickers microhardness of the clads shows similar results in both material feeding techniques, as indicated in Figures 11 and 12. The hardness in the heat affected zone in the steel plate shows higher values compared to the rest of the substrate due to structures of martensite, caused by the heating and rapid cooling, Figure 11. The higher laser power, the more the heat affected zone gets modified, the harder is the measured value.

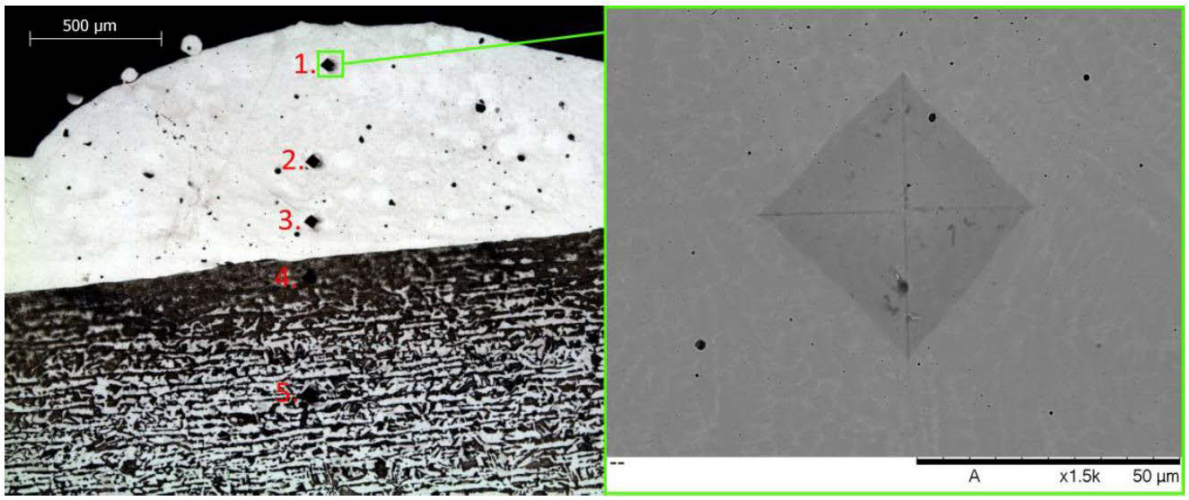

Figure 11. Localization of the Vickers hardness measuring positions in the clad and substrate (left) and a single indentation mark in the clad (right).

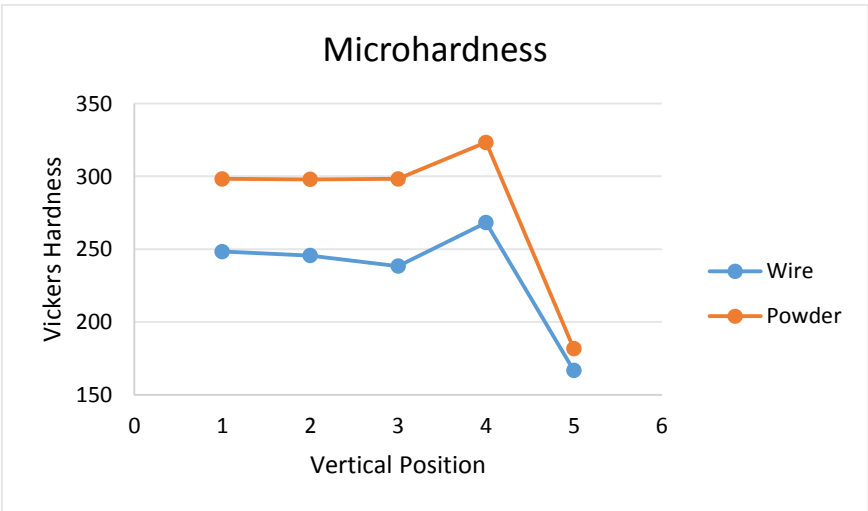

Figure 12. Microhardness (Vickers) of wire- and powder feeded overlapped clads.

The scanning electron microscope (SEM) analysis shows that the results of the optical analysis are congruent with the chemical composition analysis of the coated surfaces. A track line through the coating surface down into the substrate is measured to get the chemical composition, especially of the border in between the coated layer and the substrate, Figure 13.

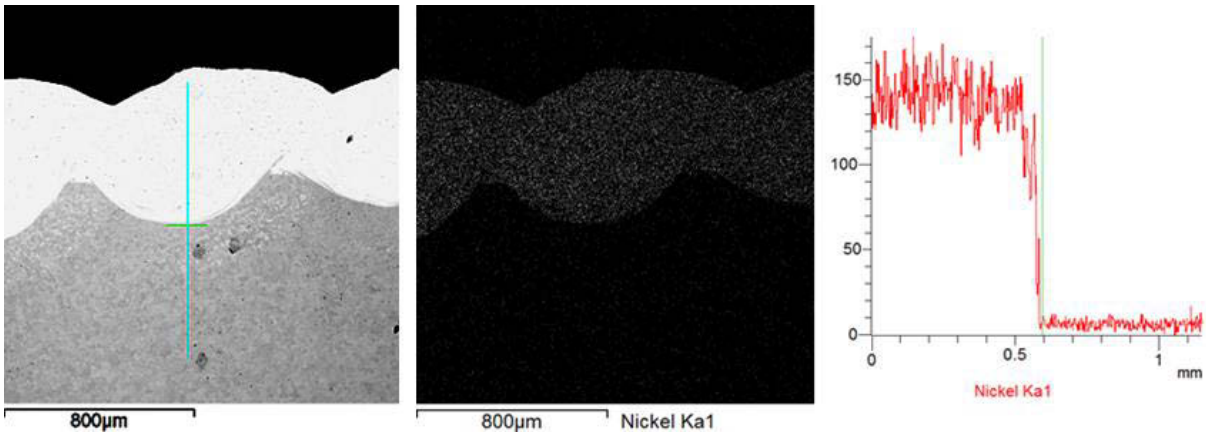

Figure 13: SEM Analysis – Distribution of nickel in the clad.

Figure 13 shows the track line analysis and the localization of the nickel presence. Nearly all the nickel is present only in the coating and quite any dilution is verified into se steel substrate.

The decrease of the nickel presence is abrupt along the track line at the border between the coating and the substrate. This step indicates, that quite no nickel is lost from the coating to the substrate during the laser cladding process. When tracking for iron it is verified that happens a relative high displacement of iron from the substrate into the clad when using high laser powers, Figure 14. This iron presence is not desired in the clad and can harm the desired protection of the coating. In all the experiments carried out, no iron was verified at the surface of the clad.

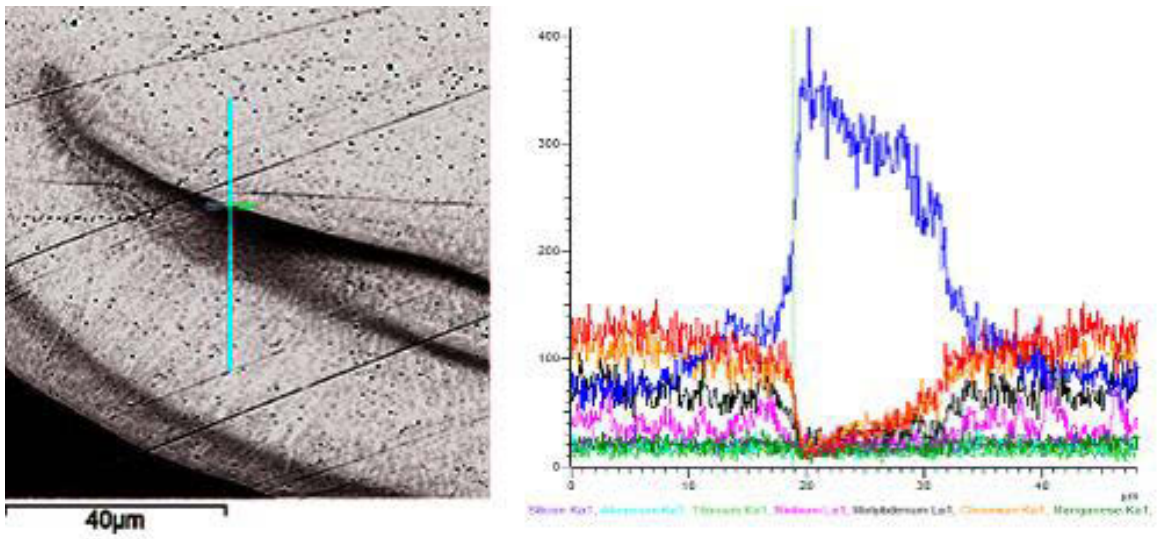

Figure 14:Distribution of iron in the clad.

4. CONCLUSION

Comparing both laser powder and laser wire cladding techniques, some differences are verified. The powder feeding laser cladding results in better results with lower feeding rates and lower laser powers, resulting in coating surfaces with very low dilution and small heat affected zones. Whereas the wire feeding process gives better results using higher laser powers and feeding rates, with potential to even higher deposition rates. In both processes the parameters for the pair - cladding and substrate material - must be optimised by more extensive experiments to guaranty a stable and repetitive process to replicate results for big cladded areas.

Both material feeding for laser cladding techniques have potential to be improved using more adequate laser sources and feeding procedures, e.g. double wire feeding, hot wire feeding or a powder feeding system with a higher feeding rate, with the claim to multiply the productivity. The background application of a protective clad layer is fulfilled by both methods. All in all, there are no restrictions that prevent further researches and the final application of both processing techniques on their broad field of application.

5. ACKNOWLEDGEMENTS

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