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Article 3: Trends in the Technology; Part 2

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In this article, we jump more into the technical details and get an overview of laser cladding spot sizes, deposition speeds and overlap behavior.

It is probably right to start with the comment that there is no best or worst direction for the technology. All three directions — high-speed, high-power and 3D laser cladding — have their advantages and disadvantages. There is no panacea available and the selection of the solution is primarily dictated by the requirements of the specific application. Let me give you an example. Imagine you have a cylindrical part, let's say a tube of 2000 mm (78.7 in) in length. It would be an exaggeration to use a high-power cladding process with a rectangular spot if you need a thin 200 µm (7.8 in) coating on the surface of that body. You would hardly end-up with the required thickness. On the contrary, if you need a 1.5 mm (0.06 in) thick coating on the same part, the EHLA solution would require a multi-layer deposition resulting in longer production time. Besides, not all of the materials can be deposited in 4 to 5 layers. In fact, there might be some people who would not even choose laser cladding technology and prefer a thermal spray or some other available method of surface protection. Let's be honest, the economic aspects are and will always stay as the main driving force for the industry. That means not only production costs but also investment costs have to be considered.

A Little Bit of Theory

First of all, let's have a short look at typical terms that are important for the laser cladding process.

- **Laser Power** is the amount of energy introduced to the surface of the substrate. It also indicates how much filler material we can melt. With increased power we can use higher velocities and with a bigger spot.
- **Spot Size** indicates the width of the coating. Spot typically can have one of two geometries — circular or rectangular. Usually the width of the cladding bead is equal to the diameter of the circular spot (or width of the rectangular spot). That means if you have a spot of 1 mm (0.039 in), we can expect to get a single laser cladded bead of the same width. Note: depending on the material wettability with surface and type of laser (beam quality and possible Gaussian function) the dimension between the real coating width might vary a little from that of the theoretical. Therefore, it is recommended to measure the real coating width when developing qualification process parameters for your application.
- **Step and Overlap** are terms that are commonly used together and are commonly mixed which might lead to a misunderstanding. Basically, if we need to cover a larger surface we will need multiple cladding beads to achieve that. Whether if we work with a circular or rectangular spot the geometry of our bead in cross-section looks like half of an ellipse or a segment. That means to keep the required consistent coating thickness over the entire cladding area we need to overlap the beads with each other. In Figure 1 I have tried to show the difference schematically and explain the difference in the terminology. The step is a distance from the center of the 1st bead to the center of the 2nd bead. Overlap indicates how much the 1st and 2nd beads interact with each other (that is also the area where additional heat input is introduced). Step and overlap values do mirror each other and their summary is equal to the coating width. By playing with those values, the productivity of the process and the thickness of the final coating are controlled. Usual values for the circular spot are between 40 % to 60 % for overlap.

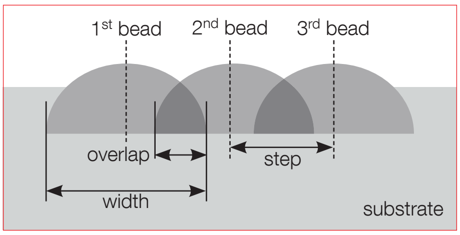


Figure 1: Graphical explanation of Step / Overlap / Width

- **Deposition Efficiency** (DE) indicates the percentage of the total powder used that lands in the melt pool and therefore builds the coating. Lower DE means less efficient material consumption.
- **Feed Rate** indicates the amount of filler material delivered to the melt pool per defined amount of time. For powders typical values are given in g/min or lb/h.
- **Coating Thickness** per pass indicates the thickness we can achieve. It is also important to differentiate between gross and net thickness. As we do work with overlapped beads, it results in the formation of minimum and maximum thickness values. The proper way of measuring thickness is shown in Figure 2.
  - The best way to identify coating thickness is to view it in cross-section.
  - The coating measurement thickness starts from the substrate line, which is considered to be the "zero" point.
  - Minimum coating thickness is equal to the net thickness of the coating.
  - The difference between maximum and minimum values helps to estimate the required coating thickness tolerances needed for post-coat machining.
  - The difference in thickness is influenced by the percent of overlap. For

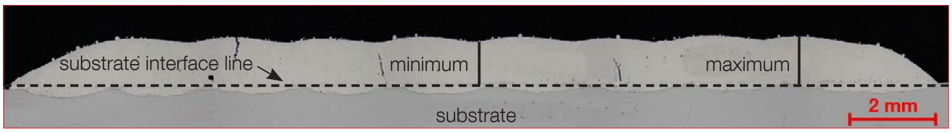
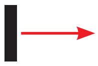
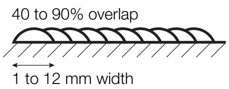
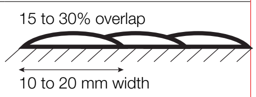


Figure 2: How to measure a coating thickness

Data	Conventional	High-Speed or EHLA	High-Power Circular	High-Power Rectangular
Spot geometry	circular	circular	circular	rectangular
Typical spot size (mm)	0.5 to 6	< 2 EHLA 2 to 5 (HP-EHLA)	5 to 12	12 to 40 long by 3 to 7 wide
Typical velocity (m/min) [a]	0.2 to 3	20 to 200	1 to 10	0.2 to 3
Typical energy (kW)	1 to 8	1 to 10	5 to 20+	8 to 20+
Typical DE (%) [b]	60 to 95	80 to 95	60 to 95	60 to 90
Typical feed rate (g/min)	5 to 100	5 to 150	40 to 150	40 to 300
Powder cut (µm)	-150 +45	-53 +20	-105 +45	-105 +45
Typical thickness (mm)	0.5 to 1.5	0.05 to 0.35	0.6 to 2.5	0.8 to 5
Overlap (%)	40 to 60	60 to 80	40 to 60	10 to 30
Spot view				
Overlap view				

[a] High-speed velocities (> 5 mm/min) work only for rotationally symmetrical bodies
[b] DE = Deposition Efficiency; values depend on the nozzle design, cladding strategy and part geometry.

Figure 3: Summary of important values for the Laser Cladding technologies.

EHLA technology, for example (also due to 80 % overlap), the difference values can be below 100 µm (0.004 in) For conventional laser cladding, those values are typically between 300 to 400 µm (0.012 to 0.016 in).

High-Speed vs High-Power

In Figure 3 I have tried to summarize all of the different parameters and properties that are typical for each laser cladding method. Please note that these are approximate values as the information from the different sources for one or another parameter might vary (and I might have missed some of the research scale values).

With a rectangular spot it is possible to cover the biggest surface in a single pass. Also, the overlap requirements are usually below 30 %. On the other hand, the deposition velocity is generally low and the big spot has to be compensated for by the energy. For example, to work successfully with a 19 by 6 mm (7.5 by 0.24 in) spot, you would require a 15+ kW laser source. Furthermore, in the past it was not always easy to control the coating quality in the overlap area. Recently there has been a lot of work done to improve that and the latest generation nozzles look very promising. Although I still have concerns about how these optical components and cladding nozzles behave under 20 kW laser power and 8 to16 hours of daily operation, there are already some companies that are laser cladding with that intensity so there is a solution available.

A high-power circular spot is a more powerful version of conventional laser cladding. It offers a combination of good productivity, a stable process and the flexibility of geometries that can be treated. This method, in my opinion, has strong potential and can be very competitive with EHLA or the high power rectangular method of deposition. Also, the lifetime of optical components and work instruments should be considered.

In the case of EHLA, the main developments go into increasing the feed rate. in 2019, the maximum capacity of nozzles was around 30 g/min. Now, with new generation nozzles (June 2020) the a capacity of over 100 g/min can be achieved, strongly influencing productivity.

Another limitation of EHLA is related to the treatment of rotation symmetrical bodies only.

Right now the majority of companies on the market are still working with the conventional Laser Cladding process – it is stable and safe, well-established, and fulfills most of the requirements. However, considering economical demands and benefits for certain applications, I am sure there will be more and more companies showing interest in trending developments. It is also worth to mention that every conventional laser system can be updated/modified for the application in the high-speed or high-power segment, which makes such an investment more attractive.

In 2018 I participated in a project where we compared the productivity of different methods and now I want to share the summary with you. The idea was to look at and compare what was achievable at that time with EHLA, high-power circular, and high-power rectangular methods of deposition. I have also added corrected (theoretical values), considering the developments for high-power EHLA in the last two years. For the investigation, simple pipes of a diameter of 60 mm (2.36 in) and length of 1000 mm (39.4 in) were selected It is also important to mention that the wall thickness of the pipes was below 5 mm (0.2 in), therefore the process parameters were chosen accordingly, as listed

Data	EHLA 2018	EHLA 2020 [b]	High-Power Circular	High-Power Rectangular
Spot size (mm)	1.0	1.5 to 2.0	12.5	19 x 6
Deposition velocity (m/min)	30	100	1.5	0.8
Power (kW)	2	5	8	10
Feed rate (g/min)	30	100	90	130
Number off layers	2	4 (theoretical)	1	1
Coating thickness (mm)	0.35 per layer	0.25 per layer	1.0	1.0
Coating time (min)	21 per layer 42 total	5 per layer 20 total	21	13
Deposition efficiency (%)	95	+5	95	90
Surface roughness [a]	very smooth		smooth	smooth
Porosity [a]	present between layers	low	some	low
Dilution [a]	very low	very low	low (controlled)	less controlled
Min/max thickness Δ (mm)	< 1.2	< 0.1	0.15 to 0.2	0.15 to 0.2

[a] Relative values
[b] Theoretical results

Figure 4: Summary of process data for EHLA, HP EHLA, HP-circular spot and HP-rectangular spot

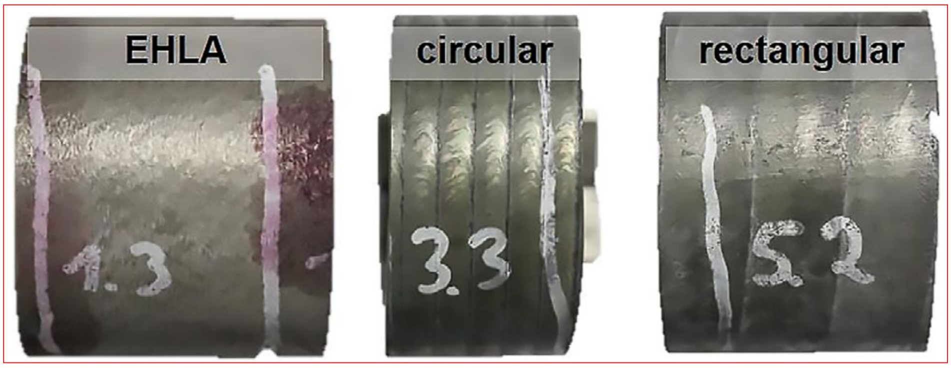


Figure 5: Surface topography of tubes after laser cladding

in Figure 4. We worked with diode lasers for all the deposition methods. The main goal was to achieve about 1 mm (0.04 in) of Inconel 625 coating and to look at the productivity values of all the technologies.

Results have shown that feed rate and laser power has a significant impact on process productivity. High-power lasers could achieve the required coating thickness in a very attractive time interval. A couple of positive takeaways were related to the high deposition efficiency (over 90 %) and a very smooth surface (especially considering the bigger spot areas and overlap requirements). The surface images for all three investigated parts are presented in Figure 5 and cross-sectional images in Figure 6. For all three methods, a very smooth surface was achieved. The difference between maximum and minimum thickness values were 0.15 to 0.20 mm (0.006 to 0.008 in) for high-power methods and below 0.1 mm (0.004 in) for EHLA. The measured average hardness values for the coating were as follows:

- EHLA: 285 HV
- High-power circular: 230 HV
- High-power rectangular: 240 HV.

The general hardness increase of 15 to 20 % for the EHLA method can be explained by extremely rapid cooling. For the EHLA process, the achieved results did not deliver the top score. Due to the relatively small diameter of the parts and limitations in the rotation speed, a maximum deposition velocity of only 30 m/min (98.4 ft/min) could be achieved. Another limiting factor was related to the feed rate of only 30 g/min (4 lb/h), both resulting in relatively low (compared to high-power) processing time and the requirement for multi-layer deposition. As an advantage, I would mark a very smooth surface and generally higher hardness values for the Inconel 625 coating.

Furthermore, considering the developments in the EHLA process and presented theoretical values (as state of the art) the possibility to apply that process can be comparable to high-power deposition methods in terms of productivity, compensating for the number of required layers by high-deposition velocity.

Summary

As you can see, all three methods of deposition have their merits, and also for all of the methods there is still room for improvement. I am looking forward to seeing how the technology will continue to develop, and how those trends can be successfully implemented in production for a wider range of applications! ■■■

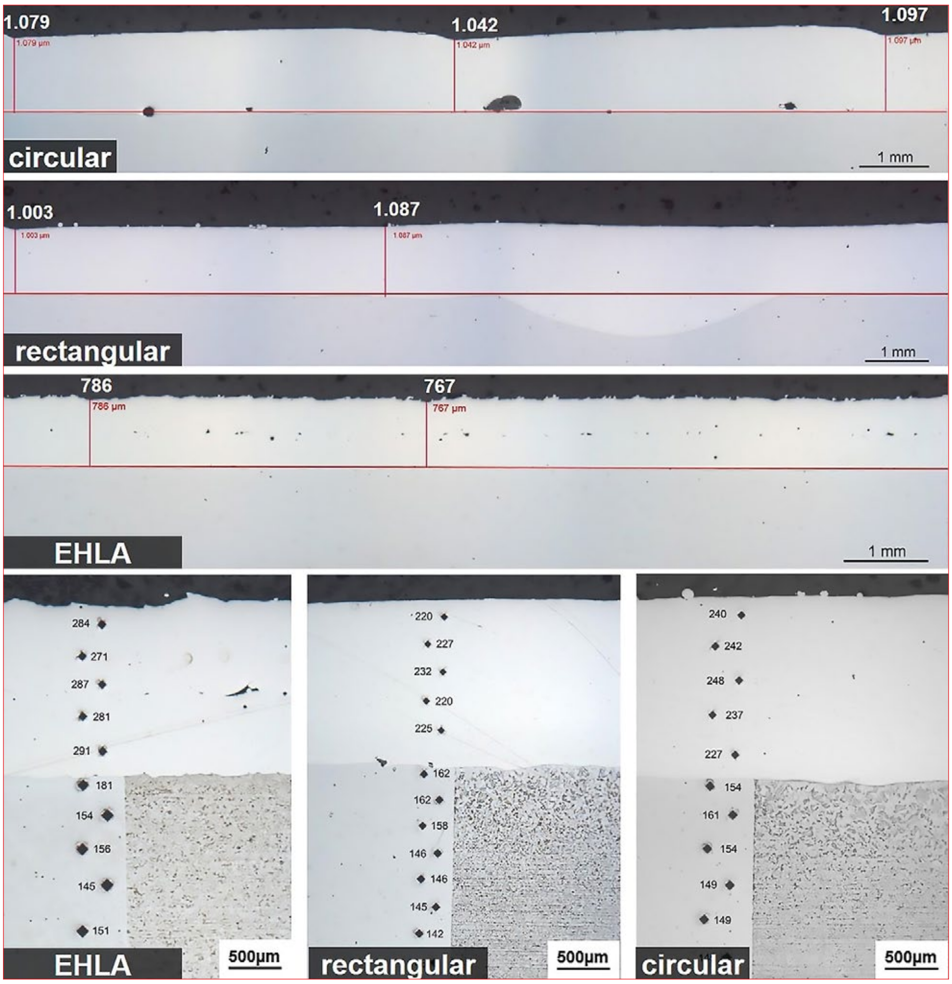


Figure 6: Cross-sectional micrographs, and hardness distribution values for tubes after laser cladding

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