

DEPOSITION STRATEGIES REVIEW IN THE LASER CLADDING CONTEXT

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Abstract. *Laser cladding technique is being applied on a variety of fields such as petrochemical and gas industry, recovery and protection of turbine blades for the aero and energy companies. However, the technique still faces some challenges, specially related with the geometric quality deposition. Therefore, the aim of this paper is a data review of coating technique, which can help to improve laser cladding technique. As the coating tracks are relatively simple in comparison to additive manufacturing in general, there is no much articles concerned with this topic devoted to laser cladding. The data review will focus on the nearest process related to laser cladding coating issues. First, the improvement of general purpose CAM system applied to a multi-axis laser cladding and the inconvenient caused by the interactions of the trajectories. Then, a different order to deposit the beads is proposed, as well as possible benefits are presented. Finally, the capabilities of new geometrical model are shown to be very useful to understand and predict the clad beads and deposition shapes.*

Keywords: *Laser Cladding, Deposition Strategy, Geometrical Modeling.*

1. INTRODUCTION

Laser Cladding is variant process for Laser Metal Deposition (LMD) where 3D components are produced by melting the material to be deposited, which can be powder or wire, using a laser energy. The deposition material is injected coaxially with the laser beam creating a melt pool over the substrate forming layers of solid material (MAHAMOOD, 2018). LMD and laser cladding are treated as synonyms for many specialists but, while laser cladding is focused on coatings – either for surface protection or component recovery – LMD is a more general process which includes solid components fabrication.

Laser cladding technique relies on many variables. Besides the optimization of parameters, appropriated path strategies are fundamental to reach acceptable deposition quality. The major input factors such as, laser beam power, mass flow, powder feed rate, traverse speed and spot diameter are decisive for the final quality. In addition, layer geometry and deposition strategy can greatly affect the resultant dimensions and microstructure (HUA; CHOI, 2005).

Heat is inherent to laser processes, in this sense, the temperature distribution and the deposition strategy are closely related (YU et al., 2011). Besides the path, the order of the bead deposition is very important, because it affects the material solidification and crystallization mechanisms (ROTTWINKEL *et al.*, 2017). Even the microstructure can be controlled by the deposition strategy, this fact demonstrate how important is the knowledge about deposition strategy and clad geometry.

For multi-layer deposition, the height deviation is critical, because the position for the next layer is not uniform and the process can become unstable (CALLEJA et al., 2014). Also, as the number of layers grows up, precision and thermal conditions tend to deteriorate. This effect is caused by the amplification of small defects in the previous layers. Particular deposition strategies can be applied to reduce the growth of flatness defects (HUA; CHOI, 2005).

Finally, the determination of mathematical functions for a bead cross section profile is central to develop a proper numeric model (OCELÍK et al., 2014). Simulation by itself is precious for laser cladding, because it can predict the final clad shape reducing the number of experiments and waste of valuable resources.

2. DEPOSITION STRATEGIES FOR LASER CLADDING

There is no much articles concerned specifically with deposition strategies or pathways for laser cladding. One reason to explain this fact is that the pathways for laser cladding tends to be simpler. In contrast, the paths used for other additive manufacturing in general are much more elaborated, such as for SLM for instance. This doesn't mean that the deposition strategy doesn't play an important role for laser cladding final quality. Based on that, this paper review articles focused on the laser cladding deposition, bead geometry and numeric models for single layer Laser Cladding. The first layer is very important for many reasons. First, because it affects the next layers – the surface defects and imperfections are amplified as the number of layers grow, and the process can became unstable at a certain point. The second reason is the relationship between the coating layer and the substrate. The interface between them is critical in terms of adhesion, cracks, pores, dilutions and other interactions (KERNINON, 2008).

2.1. Strategies tests for multi-axis laser cladding

When laser cladding is applied for direct manufacturing of complex shapes recovery it is necessary a 3+2 axis kinematic. This fact demands the process to be performed in a five continuous kinematic. The practice of five-axis laser cladding is a challenge considering the characteristics involved and the absence of dedicated Computer-Aided Manufacturing (CAM) software's. Industrial solutions are based on trial and error and hand programming optimization, because optimal path strategies as well as control on five axis laser cladding parameters are hard to achieve. The deposition strategy is currently studied just for 3 axis (CALLEJA *et al.*, 2014).

In the following study, quantitative indicators taken into account are the deposition rate, the wetting angle, height and width deviations. Different toll paths were designed using commercial CAM software devoted to machining operations (Siemens NX7.5). The deposition was carried out over a semi sphere surface, nine different tools paths were generated and applied using a coaxial laser cladding head. Height deviations are more important than width deviations, since width deviations can be solved by changing the clad overlap. Height deviations can cause defects on layer interface. So, height deviations are more critical for multiple layers because the deposition for the next layer is not uniform and the process can become unstable.

Some inconvenient can be found in these strategies: for the zig-zag strategies the tool path cause undesirable overlapping. The radial depth is not consistent and the material is accumulated at the corner. This effect leads to an extra material deposition and surface heating. The standard contour strategy is not able to follow the surface edge geometry, this can cause and extra and unnecessary deposited material. All this issues are illustrated on the Figure 1.

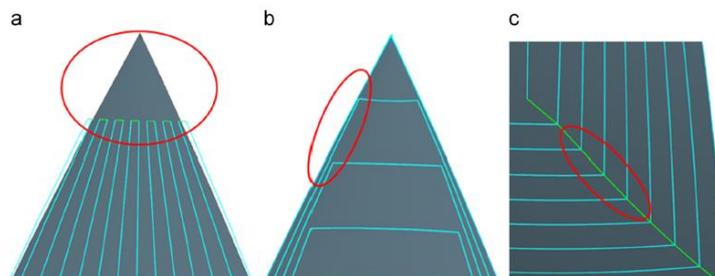


Figure 1. Tool paths inconsistency (CALLEJA *et al.*, 2014).

The study stands that the use of conventional multi axis interpolation remains a challenge for complex geometries in terms of processing parameters and strategies. This conclusion adds more evidence to the necessity of deposition strategy studies.

2.2. Single-crystal by laser cladding

The most common cladding path used – which consists of overlapping one track directly to the next one – results in a misalignment of the thermal gradient because heat is drained between the previous track and the substrate. This fact can cause pore formations and cracks (ROTTWINKEL *et al.*, 2017). One solution to this problem is done by a gap between the beads, and on a second stage, the gap should be filled. The first tracks would transfer the heat to the substrate, while the middle tracks would divide the heat symmetrically positioned. By setting up an appropriate distance between the clad lines, it is possible to avoid acute angles and a proper heat drainage in a way that is suitable to achieve a monocrystalline and directionally solidified clad.

Figure 2 provides a geometrical model to correlate mathematical variables, which will be used during the cladding process. The space between the tracks (s) can be defined in terms of the overlapping factor (o). According to the Figure

2, the gap area between two consecutive tracks should be close to the track's area above the substrate (A_t) – so the gap should be filled completely, in theory. A_t is subtracted from the area w times h .

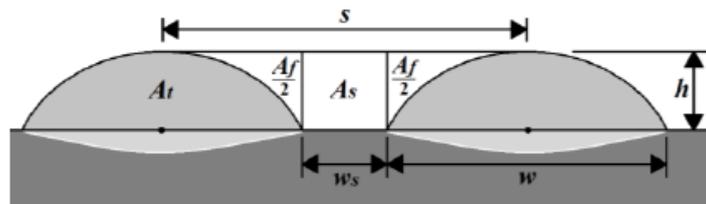


Figure 2. Geometrical model for a spaced beads (ROTTWINKEL *et al.*, 2017).

A very similar approach was used for arc welding additive manufacturing, but with a different objective – flatness defects and waviness evaluation. The strategy called “self-constrained” consist of staggering weld beads in a way that the second set of beads are constrained by the first set. The Figure 3 illustrates the constrained strategy applied in a contour setup (KERNINON *et al.*, 2008).

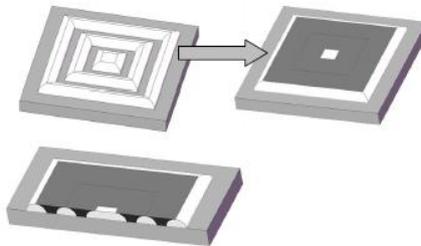


Figure 3. Constrained strategy coupled with contour for arc welding (KERNINON *et al.*, 2008).

A positive effect was obtained for this type of strategy in terms of flatness defects and could be very promising if it was applied supported by the previous mathematical model for laser cladding.

2.3. Numeric models

Numeric models are valuable to understand the deposition geometry. The literature is abundant in the topic. Most of the articles are concerned about the prevision of the beads geometry based on the input process – laser power, powder flow and physical proprieties of the powder.

In terms of bead cross section profile, there are many functions – ellipse, parabola, sinus and arc – that could fit to a single track clad. The Figure 4 illustrates the result of an experiment plotted against the model functions, also the residual values on the bottom of the image. For this particular case, the parabolic shape function gives the smallest residual. The author also concludes that for an h/w ratio between 0.05 and 0.25 the parabolic shape is the most suitable to describe the shape of clad single laser tracks (OCELÍK *et al.*, 2014).

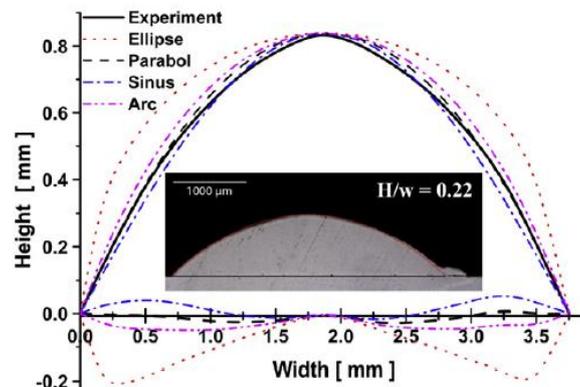


Figure 4. Experiment plotted against the model curves (OCELÍK *et al.*, 2014).

Many physical phenomena influence the formation of the shape of a bead such as gravity, electromagnetic force, viscosity, surface tension, Marangoni flow, dilution with the substrate and directional solidification. The prediction of overlapping tracks can be even more challenging. A model, illustrated on the Figure 5 aim to predict the coating geometry only by geometrical shape of a single track experimentally observed. In general, the assumption assumes the parameters provide a regular, reasonable smooth and well adhered track with constant powder feed.

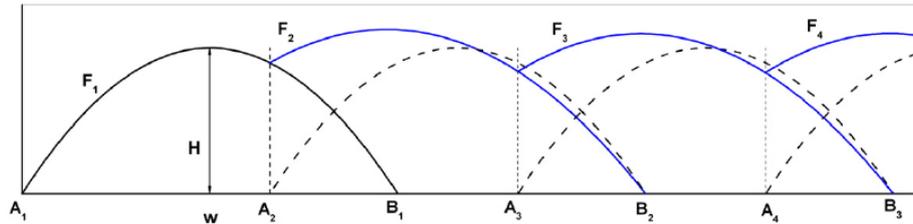


Figure 5. Geometric model proposed by Ocelík (OCELÍK *et al.*, 2014).

A visual comparison between experimental single track-coating overlaid by a parabolic shape function and recursively calculated coating profile can be seen on the Figure 6. An almost perfect match between the experiment and the curve can be verified. The mismatch at the beginning and at the end of the clad can be attributed to a gradual increase on the substrate temperature.



Figure 6. Comparison between a calculated profile deposition and an experimental deposition (OCELÍK *et al.*, 2014).

The model can be expanded to predict the deposition geometry for multilayer coatings formed by overlap of individual beads according to Figure 7. The prediction is based on a 2D cross section model and experimental processing parameters such as scanning speed, laser power, feeding rate and the displacement between consecutive tracks. Experiments show that the second substrate presents a different behaviour when compared with the first one due to cladding on the previous layer. A 15% correction thickness for upper layer was applied (NENADL *et al.*, 2016).

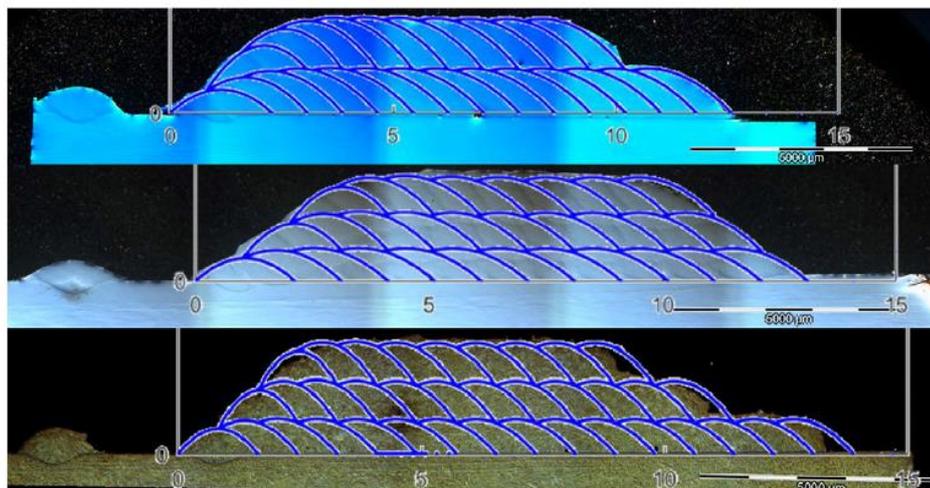


Figure 7. Cross section of a multi-layer plotted against the geometrical model (NENADL *et al.*, 2016).

Wang *et al.* (2017) developed an analytical model and experiments to estimate the bead geometry – width, depth and height – based on process parameters – laser power, powder feed rate and scanning speed. The experimental results agreed with the model with reasonable accuracy. The authors suggests considering the change on the surface tension and replacing the powder particles usage to improve the accuracy of the model. Other articles regarding to the same subject can be found, evidencing that the cladding dynamics can be mathematically predicted with a reasonable accuracy.

3. CONCLUSION

The laser cladding deposition strategy cannot be neglected considering the outputs that can be achieved. The way that the material is deposited affects the heat gradient, which by itself is central – the heat affects the substrate distortion, crystallization, solidification and cracks – the surface quality of the clad, internal defects etc. In this context, the understanding of the interaction between the beads can help the development of CAM technology dedicated to laser cladding. Techniques used in other fields can be also relevant to the laser cladding, such as in the arc welding process – since welding is previous developed, it can serve as a guide for LMD. Numerical models are also very important in this sense, not only to predict the cladding behaviour, but also to assist the comprehension related to the geometry of the beads. This is an important step to assist the development of CAM software's for commercial use – since they still in developing phase.

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