Lasers in Manufacturing Conference 2015

Build-up strategies for generating components of cylindrical shape with laser metal deposition

Torsten Petrat [a,*], Benjamin Graf [b], Andrey Gumenyuk [a,b], Michael Rethmeier [a,b]

[a]*Federal Institute for Materials Research and Testing, Unter den Eichen 87, 12205 Berlin, Germany*
[b]*Fraunhofer Institut for Production Systems and Design Technology, Pascalstraße 8-9, 10587 Berlin, Germany*

Abstract

Laser Metal Deposition (LMD) as additive manufacturing process offers the potential to produce near net shape components. This reduces the amount of material and post-processing. The components are composed of individual layers. Already small irregularities within a layer can add up over multiple layers and lead to error propagation. This paper deals with the issue of build-up strategies to minimize irregularities and prevent error propagation. Different travel paths and the influence of a changing starting point regarding to error propagation are discussed. Different deposition rates between core and peripheral area are detected and successfully compensated by adjusting the build-up sequence. Stainless steel and titanium alloy Ti-6Al-4V are used in the experiments. The results are intended to illustrate the potential of an adjusted build-up strategy and provide basic information on the way to an automated deposition process. This paper is of interest for engineers in industry or science using LMD as additive manufacturing process.

Keywords: Additive Manufacturing; Build-up Strategy; Laser Metal Deposition; Stainless Steel, Ti-6Al-4V

1. Motivation / State of the Art

The industry demands a tool-free production to minimize the time to market as well as to make small batches profitable. In this case additive manufacturing processes like selective laser melting (SLM) and laser metal deposition (LMD) gain more and more attention. The economic potential is reported by Wohlers, 2011. These new manufacturing processes need a rethinking in research and development for an adapted design, Vayre et al., 2012. As with other manufacturing processes, the accessibility of work space is of

* Corresponding author. Tel.: +49-30-8104-4622; fax: +49-30-8104-1557.
E-mail address: torsten.petrat@bam.de.

concern. To automate the LMD process in required positions it is necessary to understand deposition and design build-up strategies for different specifications.

One layer can be built by different travel paths. A common way to build a layer is a track moving along the contour followed by a pendulum strategy to fill the interior, where the single tracks have the same alignment, Rombouts et al., 2013. It is relative simple to create travel paths for geometrical forms with straight and perpendicular edges. Challenges are found by shapes with different pitch angles like circles. The track size is an important design parameter in that case, because it affects the resolution or rather the deviation of the specified shape, Wilson et al., 2014. To increase resolution, it is possible to use parameters, which lead to a smaller track width by a similar track height. The influence of different welding parameters on width and height are investigated by Graf et al., 2013. The main issue by this method is the generally lower deposition rate compared to bigger track sizes, which lead to a lower productivity. Another way is to adjust the travel path by lane change from one track to the next, Zhang et al., 2003. A difficulty is caused by a changing overlap in the area of lane change, because the overlapping affects the height of adjacent tracks and thus an even layer, Zhang et al., 2007.

An even layer is necessary in order to produce components which consist of many of these superimposed layers. Irregularities add up over multiple layers and lead to error propagation and can influence the mechanical properties, Kaierle et al., 2012. Areas with different deposition rates must be identified to control the error propagation. Hensinger et al., 2000 studied a lower deposition rate in edge areas and showed the possibility of an inclined position of the powder nozzle. This requires free space to prevent collisions with surrounding parts as well as a powder jet, which will not be affected by inclination.

A circle or spiral strategy avoids the resolution problem. The component edge defines the outer travel path. The cylindrical shape allows the use of decreasing circles to fill the layer. An issue is given by the inner circles due to the long welding in a small area and a consequent heating-up. In addition, the acceleration of the axes in small circles is very high and can adversely affect the accuracy of the movement. A rotation of starting and ending points are needed to compensate different deposition rates and build a tube-shape component with an even top surface over multiple layers, Zhang et al., 2003. This rotation is not given by the center of the circular area, where the starting or ending points would be.

2. Experimental

2.1. Laser metal deposition

The experiments were conducted with a TRUMPF TruDisk 2.0 kW Yb:Yag laser and a 3-jet powder nozzle. The carrier gas for powder transportation is Helium 5.0 with a flow rate of 4 l/min. The shielding gas is Argon 5.0 with a flow rate of 10 l/min. Stainless steel similar to 316L and titanium alloy Ti-6Al-4V with a powder grain size of 45-90 µm have been used in the experiments. The nozzle position is in all experiments perpendicular to the top surface of the specimens. The used welding parameters are listed in Table 1.

Table 1. Welding parameters

Welding parameters	316L	Ti-6Al-4V
Laser Power P in W	1200	1000
Spot diameter d in mm	2.2	1.0
Welding velocity v in mm/min	500	1000
Powder mass flow $\dot{m}$ in g/min	3.8	3.75

All components have a minimum diameter of 16 mm and the titanium components in addition a target height of 120 mm. The components were built on a carbon steel plate of S335JR with a thickness of 6 mm and a titanium plate with a thickness of 16 mm.

2.2. Build-up strategies

Table 2. Build-up strategies

Strategy	Layer composition	Material	Starting point rotation (layer to layer in degree)	Starting point offset (circles to field in degree)
S1	Field	316L	0	0
S2	Field, circle	316L	0	0
S3	Circle, field, circle	316L	0	0
S4	Circle, field, circle	316L	35	0
S5	Circle, field, circle	316L	95	0
S6	Circle, field, circle	Ti-6Al-4V	95	0
S7	Circle, field, circle 9th layer compensation	Ti-6Al-4V	95	0
S8	Circle, field, circle 9th layer compensation	Ti-6Al-4V	95	180

In the experiments a customized pendulum strategy and combined circle-pendulum strategies are used. Table 2 shows the investigated build-up strategies with information of layer composition, material, starting point rotation from layer to layer and starting point offset from circle to field within a layer. Build-up strategy S8 is shown in Fig.1.

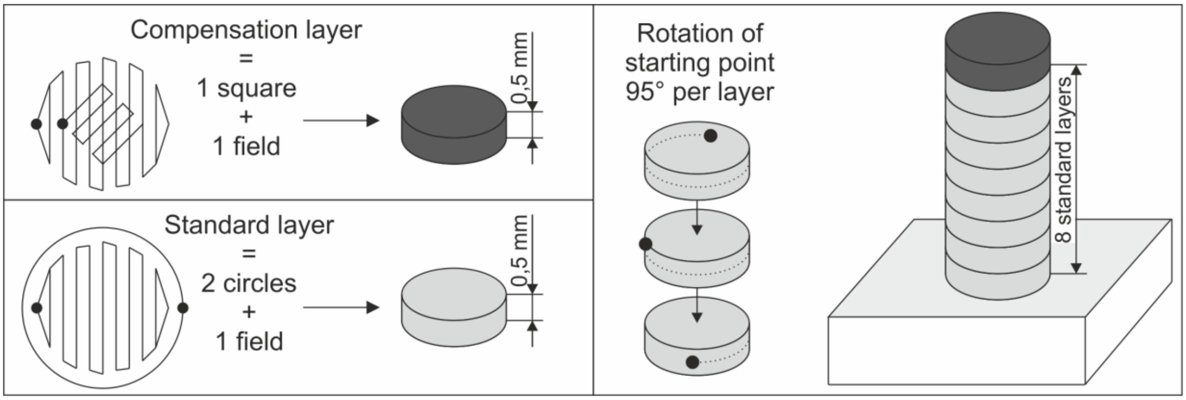

Fig. 1. Build-up strategy S8 with different layers

3. Results and Discussion

3.1. Stainless Steel

A comparison of the strategies used with 316L is shown in Fig. 2a. Strategy S1 shows small straight sections in the areas of lane change. The outer shape of S2 indicates a positive effect to achieve a near-net-shape by using a combination of pendulum and circle strategies, because the outer circle avoids the stair step effect. After 6 layers both strategies, S1 and S2, lead to a fall off of the peripheral areas and a conical shape of the resulting components. An expected peak in the area of the starting points of circle and field was detected by both strategies. The deposition of additional four outer circles is needed to nearly balance inner and outer areas. However, the resulting top surface of S1 and S2 after 6 layers is not as good as that of S3, where two circles were included in each layer. These observations support the mentioned research results of a lower deposition rate in edge areas. The separation of inner field and outer circle allows an adapted build-up sequence with different amounts of tracks to compensate the difference in deposition. A peak in the starting area was also detected by S3, which is shown in Fig. 2b.

After 15 layers the areas of the starting and additionally the stopping points of the inner field show peaks by S3 as well as a fall off of the outer area between these points. Due to the unchanging start coordinates, the different deposition rates add up over the amount of layers and results in an uneven top. This occurs every 15 layers and is shown after 60 layers in Fig. 2d. Two additional superimposed partial circles were needed to balance the height of the outer area. A rotation of the starting point in S4 and S5 leads to an even surface and shows a compensation of the peaks (Fig. 2c). The angles of 35° and 95° were selected in avoidance of repetitive start coordinates after a full rotation. The resulting components show no difference between a small and a large rotation angle.

Another positive effect was detected by a bigger average layer height by S4 and S5 with 0.9 mm towards S3 with 0.8 mm. Further, there was a slight decrease in the peripheral areas for all components, which was compensated with three to four additional circles to continue the fabrication process. A good resulting build-up sequence for S4 and S5 is:

- 5 standard layers
- 1 outer circle.

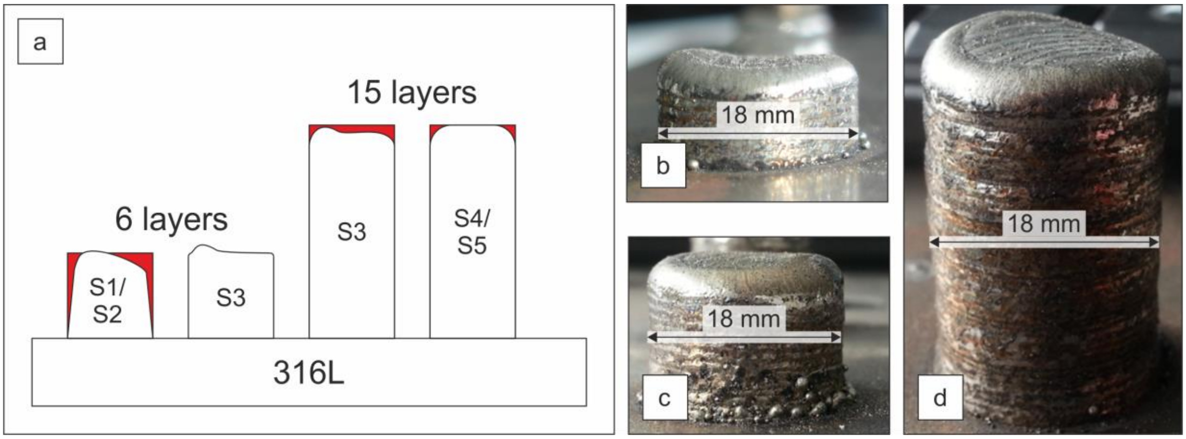

Fig. 2. Build-up of the used strategies for 316L after different amount of layers

3.2. Ti-6Al-4V

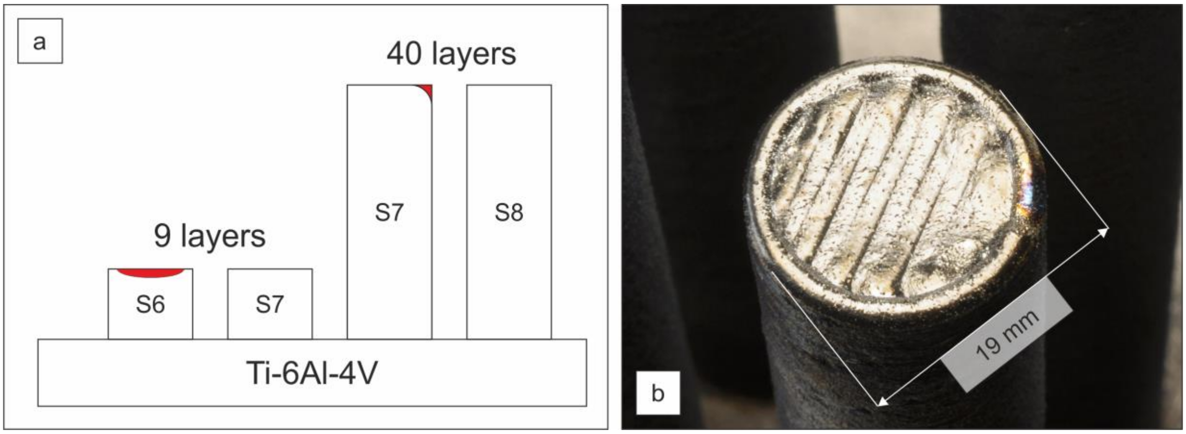

Fig. 3. (a) Build-up strategies for Ti-6Al-4V after different amount of layers and (b) even surface after standard layer

Fig. 3a shows strategies S6 and S7 after 9 layers and strategies S7 and S8 after 40 layers. S6 is similar to strategy S5, but it leads to a decrease of the middle area instead of the peripheral area. It appears that the lower deposition in edge areas has no constant factor, but depends on parameters and material. The decrease is compensated in S7 by using a modified 9th layer, which is composed of a small square and the inner field. The resulting top has an even surface. The components by S7 show a decrease of a small part of the peripheral area after 40 layers, which all point to the same direction. These were compensated by semicircles. The main issue is reproducibility. The number of needed semicircles differs between 2 to 4 by the different cylinders within a layer as well as between the layers. Furthermore, the number of layers was different before compensation became necessary and was between 20 and 40. These make regular checks and adjustments necessary, which increase the monitoring requirements for an automated process.

The offset of the starting points of field to circles by 180° within a layer by S8 lead to a constant build up without the need for additional semicircles. A resulting even surface is shown in Fig. 3b. A height of 0.5 mm per layer was detected by building the 120 mm high cylinders on a substrate plate.

4. Conclusion

This paper deals with different build-up strategies for additive manufacturing of cylindrical parts with LMD. It is possible to build components composed of over 100 layers using a perpendicular nozzle position. A steady growth has been reached with two layer compositions and made manual corrections unnecessary. Two superimposed tracks compensate the lower deposition in edge areas, but different material and track size show different error propagation. From these arise the question of the influence of the individual parameters.

It has been shown that a layer rotation of 35° or 95° lead to an even surface and avoid error propagation in start and end areas. To reach the best mechanical properties, the influence of the layer orientation is of interest. In future work, experiments with almost aligned or vertical tracks will be examined.

References

Wohlers, T. T., 2011. "Additive manufacturing and 3d printing state of the industry; Annual worldwide progress report", Wohlers Associates Inc., Colorado.

Vayre, B., Vignat, F., Villeneuve, F., 2012. "Designing for Additive Manufacturing" , Procedia CIRP 3, p. 632.

Rombouts, M., Maes, G., Hendrix, W., Delarbre, E., Motmans, F., 2013. "Surface finish after laser metal deposition", Physics Procedia 41, p. 803.

Wilson, J. M., Piya, C., Shin, Y. C., Zhao, F., Ramani, K., 2014. "Remanufacturing of turbine blades by laser direct deposition with its energy and environmental impact analysis", Journal of Cleaner Production 80, p. 170.

Graf, B., Ammer, S., Gumenyuk, A., Rethmeier, M., 2013. "Design of experiments for laser metal deposition on maintenance repair and overhaul applications", Procedia CIRP 11, p. 245.

Zhang, Y., Chen, Y., Li, P., Male, A.T., 2003. "Weld deposition-based rapid prototyping: a preliminary study", Journal of Materials Processing Technology 135, p. 347.

Zhang, K., Liu, W., Shang, X., 2007. "Research on the processing experiments of laser metal deposition shaping", Optics & Laser Technology 39, p. 549.

Kaierle, S., Barroi, A., Noelke, C., Hermsdorf, J., Overmeyer, L., Haferkamp, H., 2012. "Review on Laser Deposition Welding: From Micro to Macro", Physics Procedia 39, p. 336.

Hensinger, D. M., Ames, A. L., Kuhlmann, J. L., 2000. "Motion Planning for a Direct Metal Deposition Rapid Prototyping System", International Conference on Robotics and Automation. San Francisco, USA, p. 3095.