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Embedding electronics into additive manufactured components using laser metal deposition and selective laser melting

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Abstract

The paper deals with the integration of a light emitting diode (LED) into an additive manufactured metal component. Selective laser melting (SLM) and laser metal deposition (LMD) are used. The material used is the chrome-nickel steel 316L. The basic component is manufactured by means of SLM and consists of a solid body and an area with grid structure. The solid body includes a duct in the shape of a groove with a recess for the positioning of the power cable. The LED is embedded in the grid structure via an inlet from the solid body. In further processing, the groove is filled with LMD. Two strategies with different parameter combinations were investigated. It shows that a high energy input near the power cable leads to its destruction. By using multiple parameter combinations during the manufacturing process, this destruction can be prevented. There was a comparison of both strategies with regard to the necessary number of tracks and duration of welding time.

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1. Introduction

Today's technical applications are getting more and more complex. To satisfy requirements e.g. size, functions or long-term reliability, innovated manufacturing methods have to be developed. In order to create an interface between Measurement and Control Technology and manufactured parts, the components have to become smart. A potential way to improve the abilities of components is to integrate measuring systems into them.

Additive manufacturing processes have become very popular in recent years. They are used in many industrial areas to produce prototypes. The resulting time advantage is an important factor in keeping up with the fast pace of research and development. Through continuous improvement of processes, they are also used more and more in industrial production. Wohler shows a higher amount of sold machines in the last years [1]. The new geometrical freedom of design

offers great potential to overcome regressions of conventional manufacturing processes and to place the component function at the center of attention during construction [2].

Powder bed-based Selective Laser Melting (SLM) offers the possibility of producing complex component structures [3]. Various studies have shown how previously unfinished geometries can be produced with this process. Some examples are near net shape cooling channels for precise temperature control as well as grid structures for weight reduction [4].

Laser Metal Deposition (LMD) is also one of the representatives of additive manufacturing. Metallic substrate is locally melted using a laser. At the same time the filler material is injected by a nozzle and melts as well. The solidification results in a metallurgical bonding. The resulting tracks have different heights and widths, which can be influenced by parameters like powder mass flow, laser power and welding velocity [5], [6]. The geometric possibilities are much

more limited than with the SLM. On the other hand, LMD can be used to modify existing components [7].

Due to build up rate and the high manufacturing costs, both methods are mainly used in industrial sectors such as aerospace or turbine industry. For this reason, especially high-performance materials such as nickel-based alloy Inconel 718 and titanium-based alloy Ti6Al4V have been extensively studied [8]. Furthermore, there are a lot of publications on stainless steel 316L [9].

A combination of these two processes has already been shown [10]. Using the example of a turbine blade, the potential for increased production speed was demonstrated. The complex airfoil with integrated lightweight structures was manufactured by SLM and the solid fir tree by LMD. The use of different parameter sets was used to achieve a near net shape combined with a high build-up rate [11].

In the field of turbine industry, process monitoring at different power levels is becoming more and more important. Up to now, necessary maintenance intervals have been estimated and performed on empirical values. Downtimes must be avoided as much as possible to save costs. The measuring of process data e.g. vibrations can be used to draw conclusions about the condition of the component. This enables an on-demand maintenance based on quantitative data.

The additive manufacturing process makes it possible to integrate sensors into components and at the same time position them near the measuring point. Challenges are the high process temperatures, which are above 1300 °C for metals like Ti6Al4V [12]. In the following, the possibility of integrating electrical components is shown, which are usually necessary to record and evaluate data of sensors and actuators.

2. Experimental setup

To demonstrate the capability of processing integration technologies using LMD and SLM, the implementation of a light emitting diode (LED) into a component of 316L is investigated.

The base part is manufactured with SLM and has a solid volume of 70 x 48 x 13 mm³ with a curved 7 mm deep cable duct and a grid structure of 30 mm length at the tip. The process parameters are shown in Table 1.

Table 1. Process parameters for SLM manufacturing

Parameter set	Laser power (in W)	Welding speed (in mm/min)
SLM	250	700 to 1400

The LMD part was conducted with a TRUMPF TruDisk 2.0 kW Yb:YAG laser and a coaxial annular gap nozzle. The filler material 316L has a grain size of 45 µm to 90 µm and is gas atomized. The process parameters welding speed (v) and laser power (P) are varied, while the powder feed rate (ṁ) and laser spot diameter (d) are constant. The parameter sets are shown in Table 2. Argon 5.0 is used as shielding gas with 10 l/min and Helium as carrier gas with 4 l/min. The overlap rate is 50 % for the LMD process.

Table 2. Process parameters for LMD manufacturing

Parameter set	LPA-400	LPA-600	LPA-800
Laser power (in W)	400	600	800
Welding speed (in mm/min)	400	600	600
Spot diameter (in mm)	1	1	1
Powder feed rate (in g/min)	3,5	3,5	3,5

A green LED is attached to the end of a nickel wire, which has a fiberglass insulation that withstands a temperature of 900°C for a few seconds.

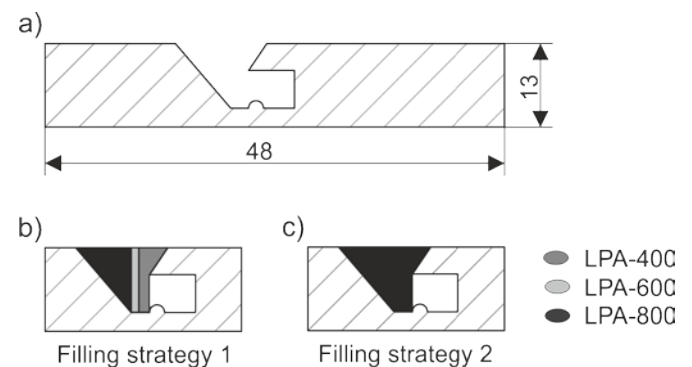


Fig. 1. a) Design of the cable duct with part dimension and different filling strategies b) with 3 parameter sets and c) with 1 parameter set

Two different strategies are tested to fill the volume of the part. In strategy 1, the deposition starts next to the wire with three tracks of parameter set LPA-400 and a fourth track of parameter set LPA-600. The remaining layer volume is built with parameter set LPA-800, Fig. 1b. The strategy repeats till the end of the manufacturing process.

In strategy 2, only parameter set LPA-800 is used to fill the volume, Fig. 1c.

3. Results and discussion

The SLM base part with the solid body and grid structure is shown in Fig. 2. The LED is placed inside the grid structure through a cable entry hole. With the design of the cable duct, the LED is 10 mm away from the welding spot, which reduce the influence of the resulting temperature. The attached nickel wire is the electronic part, which must withstand the high temperature near the melt pool. A contour welding path along the cable duct is chosen as build-up strategy to counteract a heat accumulation. The welding spot stays for a short time at one point, which ensures optimized heat dissipation. The process is paused after each track for 10 seconds. The component can cool down, which also has a positive effect on the resulting temperature.

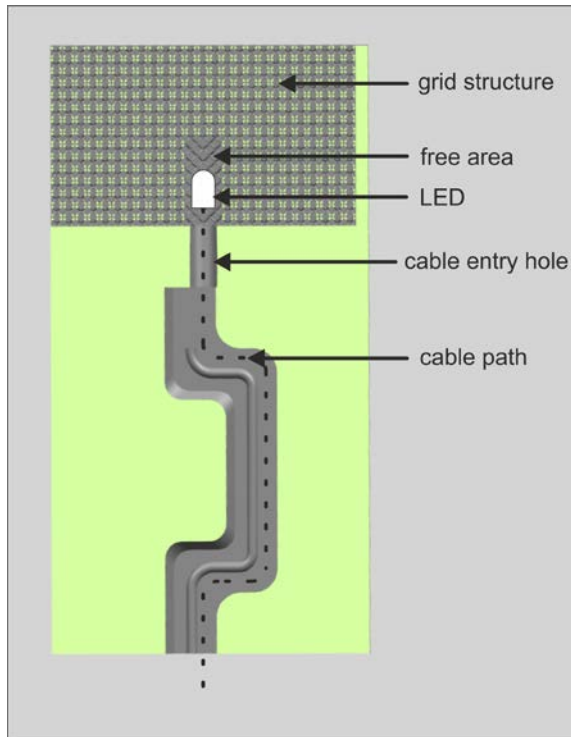


Fig. 2. Implementation overview of the LED in SLM part

Cable and LED are positioned before the LMD process starts. The prepared sample is shown in Fig. 3. The LED will turn on after each location to proof the functionality.

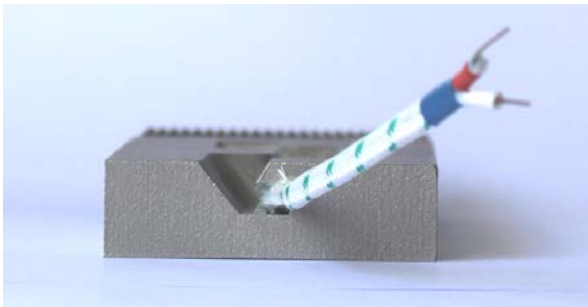


Fig. 3. Positioned cable inside the duct before LMD process.

The LMD process parameters were chosen from a database with investigated tracks for different geometries and a good metallurgical bonding. Track width and height are shown in Table 3. Parameter sets for high build-up rates and a near net shape were selection criteria.

Table 3. Resulting track size of the parameter sets for LMD

Parameter set	Track width (in mm)	Track height (in mm)
LPA-400	1.0	0.7
LPA-600	1.6	0.4
LPA-800	1.8	0.4

A calculation of the energy input per length for the different parameter sets is made with formula 1 and shown in Table 4.

$$E = \frac{P}{v} \quad (1)$$

For a low energy input with a precise material application in width, parameter set LPA-400 with a laser power of 400 W is used. The slow welding speed leads to a high manufacturing time, which is the reason to combine the different parameter sets. The parameter sets LPA-600 and LPA-800 were used with a rising distant between nickel wire and welding position. 96 tracks are necessary to fill the volume of the curved cable duct with strategy 1, Fig. 4.

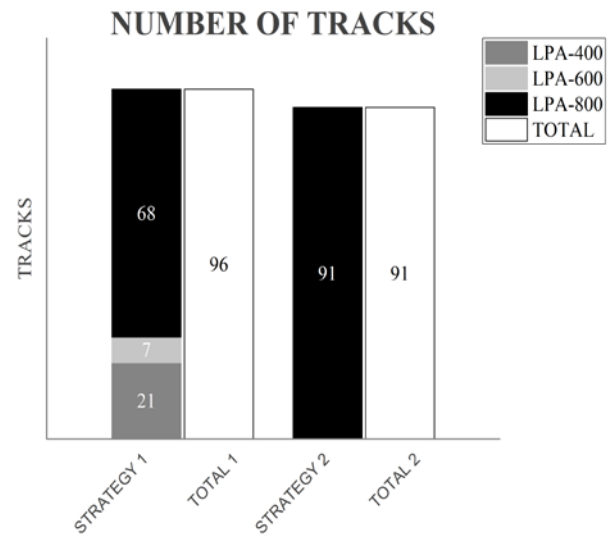


Fig. 4. Number of tracks to fill duct with strategy 1 and strategy 2.

The welding time amounts up to 17:45 min. The combined manufacturing in this way is 26 % faster than using only parameter set LPA-1.

Table 4. Energy input per length of different LPA parameter sets

Parameter set	Energy input (in J/mm)
LPA-400	60
LPA-600	60
LPA-800	80

Strategy 2 with only parameter set LPA-800 makes 91 tracks necessary to close the cable conduct. The number of tracks is 5 % lower compared to strategy 1. The welding speed of LPA-800 is 600 mm/min and consequently 50 % faster than LPA-400. The track height is lower, but therefore the track width is bigger so that the weld beads have similar volumes. The higher welding speed enables a welding time of 15:10 min, which is 15 % shorter than strategy 1 with all three parameter sets, Fig. 5.

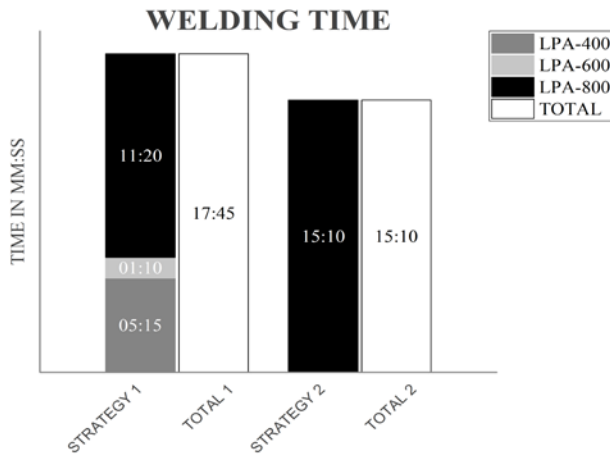


Fig. 5. Comparison of welding time between strategy 1 and strategy 2.

Because of using different process parameters in strategy 1, lower temperatures during the LMD process can be achieved next to the cable. The smaller track width of LPA-400 suggests that the melt pool is also smaller and does not reach the cable. A destruction of the components can be prevented and the implementation of the LED is successful. As shown in Fig. 6, the electronics are embedded intact in the component.



Fig. 6. Component with successfully embedded LED using strategy 1.

The calculation of the energy input per length using formula 1 shows a 33 % higher value of LPA-800 compared to LPA-400. This leads to a rise of the temperature. The tool center point is similar in both experiments. The larger melt pool size could reach the cable. The insulated wire cannot withstand it. During the manufacturing process it comes to a destruction of the wire and the connectivity to the LED is no longer given.

4. Conclusion

A process combination of LMD and SLM was successfully used to embed a LED into a metal part of 316L. The position as well as the build-up strategies show an impact to prevent the electronics from destruction. A parameter set for a fast build-up rate destroyed a nickel wire, which was attached to a LED. The energy input could be regulated when using different parameter sets for the manufacturing process. Simultaneously the welding time would not rise too much. The results show the possibility to embed electronic components into a metal part. Further investigation should focus on more complex parts with sensor integration to demonstrate its use in industrial applications.

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