Lasers in Manufacturing Conference 2015

Strategies for high deposition rate additive manufacturing by Laser Metal Deposition

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Abstract

To increase the integration of laser based additive manufacturing in the series production major challenges related to the production costs and deposition rates still need to be overcome. Laser Metal Deposition (abbr. LMD), also known as Laser Cladding or Direct Metal Deposition, is regarded as an established technology for repairing components and producing coating systems with defined properties in the petrochemical and heavy duty industry, as well as in medical engineering and aerospace. A novel promising application field for LMD is the use of the process as additive manufacturing technique.

By contrast with the powder bed technology, by means of LMD it is possible not only to generate complete parts but also to deposit defined 3D structures on existing components. In this way, an alternative to additive manufacturing from scratch is given: a combination between conventional processing and advanced laser additive manufacturing can be applied to reduce the production costs. Also geometrical modifications as well as the production of local reinforcements to adapt a basis design to different requirements can be achieved. Nevertheless, with a view to the utilization of the process in the series production, efforts have to be made to increase the cost effectiveness of the process. The present work focuses on the possibilities of LMD as additive manufacturing technology, novel strategies for the improvement of deposition rates and process efficiency being presented.

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Keywords: Additive manufacturing; surface treatment; cladding

1. Laser Metal Deposition: principle of the process

By means of Laser Metal Deposition (abbr. LMD), also known as laser cladding, a deposit material in powder form is inserted directly into a melt pool formed by a laser beam. The deposit material is continuously applied to the pool and melted. This means that both the substrate and the deposit material are melted, which results in a metallurgical bonding between the first layer and the material underneath. Powder delivery nozzles are used for the injection of the powder in the created melt pool. The layer patterns can be applied either over a large area or welded on locally, see Fig. 1.

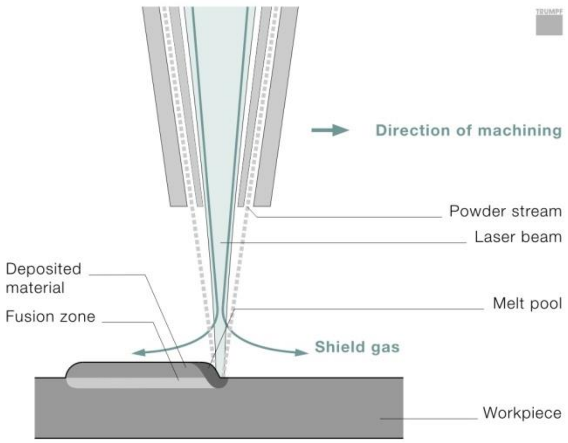

Fig. 1. Principle of the process

Various deposit materials can be used, depending on the characteristics expected for the deposition layer. FeNiCr alloys, NiCr alloys and Co alloys are used mainly in applications where corrosion resistance is a prerequisite. For armoring or hardfacing purposes, the process utilizes layer systems comprising martensitic steel, deposit materials containing carbide particles, Ni and Co alloys. Nickel and titanium based alloys play a significant role in repairing aircraft engine components. Also copper alloys as well as aluminum alloys can be deposited by using this technology.

2. Laser Metal Deposition as additive manufacturing process, comparison with the powder bed technology

The Laser Metal Deposition process is used conventionally for the production of coatings and the repair of high value components. Also joining production (aluminum to aluminum, aluminum to steel) is possible. A novel field of application is the use of the process as additive manufacturing technology, see Fig. 2.

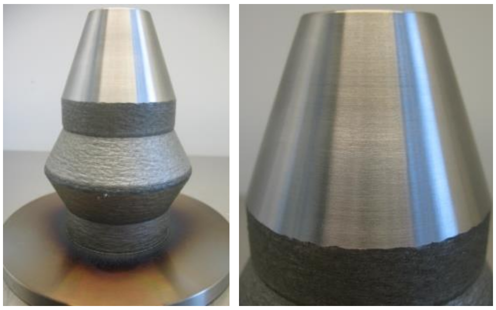

Fig. 2. (a) Part generation by means of LMD; (b) Close-up view of the part after mechanical post-processing

By contrast with the Laser Metal Fusion or powder bed process (abbr. LMF), 3D structures can also be generated on existing parts. Due to this possibility, the LMD process can be combined with conventional manufacturing methods (casting, forming a. o.) for part production. By following this hybrid approach, a basic part design is conventionally manufactured. Additional features such as 3D reinforcements or volumina to adapt the basis design to different requirements are deposited, see Fig. 3. Since conventional processing for the basic design is included in the manufacturing chain, the production costs can be drastically reduced in comparison to a pure additive manufacturing of the part.

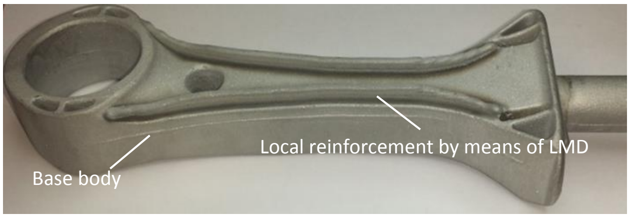

Fig. 3. Production of local reinforcements on existing parts

Material is selectively added only where required for the part reinforcement or design modification, so that weight can be saved. Beside the design, the possibility of material combination, see Fig. 4, is one major trend to achieve the required weight savings.

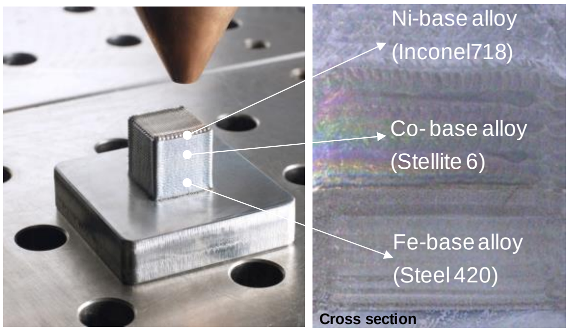

Fig. 4. Generation of 3D volume with combination of different materials

As shown in Table 1, a further advantage of LMD in comparison to the powder bed process is that higher deposition rates can be obtained. Nevertheless, as described in Section 3, efforts are being made with the aim to increase the operating efficiency of the process.

Table 1. Comparison of laser based additive techniques: Laser Metal Deposition and Laser Metal Fusion

	Laser Metal Deposition (LMD), blown powder technique	**Laser Metal Fusion (LMF), powder bed technique**
Deposition rate	Up to 300 cm^3/h (conventional) Up to 700 cm^3/h (see Section 3)	Up to 70 cm^3/h
Roughness	Ra 10-Ra 200	Ra 5-Ra 10
Dimensional accuracy	<0,5mm	<0,1mm
Part dimensions	Limited only by manipulation system	Limited by process chamber
Substrates	Conformal surfaces, existing components	Flat surfaces
Layer thickness	0,3 – 1,5 mm	0,03-0,1 mm

3. Novel strategies to increase the deposition rate

Typical deposition rates that can be achieved by LMD are in the range of 50 and 300 cm^3/h, depending on deposit material, spot size, laser power and traverse speed. Referring to this, a common approach is the use of square laser spots aiming to obtain near top-hat energy distributions on the area to be melted. In this way, in case several tracks are needed for the cladding operation, the overlapping between them can be significantly reduced.

A novel approach for the generation of the melt pool represents the implementation of a defined movement pattern for the laser spot. Preliminary tests were performed at the TRUMPF Laser Application Center (Ditzingen, Germany), aiming following goals:

- Increase the deposition rate over 300 cm^3/h for an Fe-base and a Ni-base alloy
- Flexible configuration of the shape and dimensions of the melt pool
- Near top-hat energy distribution on the area to be melted
- Use of nominal laser power up to ca. 8 KW

The experimental tests for the present work were performed by using a TruLaser Robot 5020 as guiding system for the laser optic and a TruDisk laser with nominal power of 8 KW. The laser optic was designed to enable the implementation of different movement patterns for the laser beam on the surface of the substrate. In this way, defined shapes of the melt pool could be produced. The deposit material was metered out by a powder feed device which transported the flux powder to the powder delivery nozzle using Helium as carrier gas. A COAX 11 delivery nozzle (Fraunhofer IWS, Germany) was used. A uniform powder feeding into the melt pool had to be ensured to achieve appropriate deposition quality. An additional Argon stream was applied to reduce oxidation in the weld pool. As deposit materials, the alloys 42C and Inconel 718 were considered, see Table 2:

Table 2. Powder materials used for trials

Material	Chemical composition	Grain size distribution
Inconel 718	Ni19Cr18Fe3Mo0.5Al5.1(Nb+Ta)0.95Ti0.05C	-125+45 µm
42C	Fe16Cr2Ni0.2C	-106+45 µm

Single layer and multilayer deposits were produced. Track width was ca. 14 mm. As coating thickness for the single layers ca. 2,6 mm were obtained, see Fig. 5.

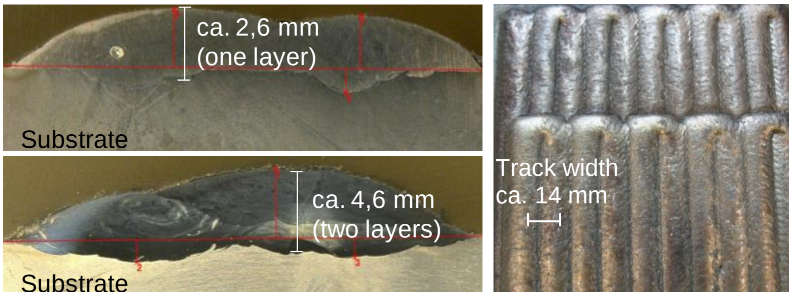

Fig. 5. (a) Fig Cross sections of one layer and multilayer deposits; (b) top view of produced coating (Inconel 718 as powder material)

The first tests showed very promising results, deposition rates over 600 cm^3/h being obtained, see Table 3. For both materials powder efficiency rates over 90% could be achieved.

Table 3. Deposition rates and powder efficiency obtained

Material	Deposition rate	Powder efficiency
Inconel 718	ca. 690 cm3/h	ca. 90%
42C	ca. 610 cm3/h	ca. 90 %

With regard to the cost effectiveness of the process, the presented approach opens up new perspectives for the Laser Metal Deposition technology in the field of coating production and for additive manufacturing applications. Further trials are foreseen in order to improve the process parameters and laser spot patterns as well as to widen the powder material spectrum.

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