Generative Manufacturing and Repair of Metal Parts through Direct Laser Deposition Using Wire Material

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Abstract. In the field of Laser Additive Manufacturing, modern wire-based laser deposition techniques offer advantageous solutions for combining the high quality level of layer-by-layer fabrication of high value parts with the industry's economical requirements regarding productivity and energy efficiency. A newly developed coaxial wire head allows for omni-directional welding operation and, thus, the use of wire even for complex surface claddings as well as the generation of three-dimensional structures. Currently, several metallic alloys as steel, titanium, aluminium, and nickel are available for the generation of defect-free structures. Even cored wires containing carbide hardmetals can be used for the production of extra wear-resistant parts. Simultaneous heating of the wire using efficient electric energy increases significantly the deposition rate and energy efficiency. Examples of application are light-weight automotive parts, turbine blades of Nickel super alloys, and complex inserts of injection moulds.

1 Introduction

Laser buildup welding is a well-established technique in industrial applications of surface cladding and direct fabrication of metallic parts. As construction materials, powders are widely used because of the large number of available alloys and the simple matching with the shaped laser beam. However, the powder utilization is always less than 90 %, characteristic values are in the range of 60 %, and so a serious part of the material is lost. Additionally, there is a risk for machine, operators and environment due to dangerous metal dust. The alternative use of wires as buildup material offers a number of advantages: The material utilization is always 100 %, and rightly independent from the part's shape and size. The process is clean and safe, and so the effort for protecting personnel and environment is much less. Also the wire feed is completely independent from the gravity which is of great advantage especially in applications of three-dimensional material deposition.

The main challenge compared to powder is the realization of an omni-directional welding operation with stable conditions of the wire supply. The only possible solution therefore is to feed the wire coaxially in the centre axis of the laser beam. This technology requires a complex optical system which permits the integration of the

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wire material into the beam axis without any shadowing effects of the laser beam itself. Accordingly, the work presented here was focused of the development of a new optics system for the practical realization of the centric wire supply as well as the related process development for the defect-free manufacturing of real metallic parts.

2 Laser wire deposition head

Based on test results of previous multi beam optics [1], a new optical system suitable for solid-state lasers (slab, disk, fiber) has been developed. The optical design of the head shown in Figure 1 is based on reflective optical elements and accommodates a power range of up to 4 kW. The laser beam is symmetrically split into three parts so that the wire can be fed along the centre axis without blocking the beam. The partial beams are then focused into a circular spot with a diameter ranging from 1.8 to 3 mm. The setup enables a coaxial arrangement for beam and wire, which makes the welding process completely independent of weld direction. The coaxial alignment is even stable in positions that deviate from a horizontal welding setup.

The wire is fed to the processing head via a hose package that contains wire feeder, coolant supply and protection gas delivery. Wire feeders from all major manufactures can be easily adapted to this setup and are selected based on wire type, feed rate, and operation mode. Typical wire diameters range from 0.8 to 1.2 mm. However, the new technology is principally also suitable for finer wires of about 300 µm in diameter. The wires can be used in cold- and hot-wire setups to implement energy source combinations. The new laser wire processing head is useful for large-area claddings as well as additive multilayer depositions to build three-dimensional metallic structures.

Fig. 1. Laser processing optic with coaxial wire supply

For process monitoring, the wire deposition head may be equipped with a camera-based system which measures dimensions and temperature of the melt bath simultaneously during the running laser process. Optionally, an optical scanning system controls the shape and dimension of the generated material volume in order to correct the build-up strategy if necessary [2].

3 Deposition process and results

Fig. 2 shows a typical laser wire cladding process during a multiple-track deposition. The process shows a stable behaviour with extremely low emissions of splashes and dust, compared to powder-based processes. The integrated on-line temperature regulation keeps the temperature of the material on a constant level during the whole manufacturing duration.

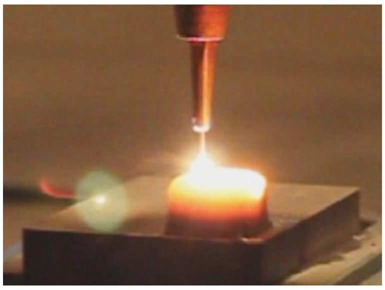

Fig. 2. Process of laser wire deposition of a metal volume

The part is built from a large number of single tracks, which are placed according to a special build-up strategy. This strategy is designed by computer calculation prior to the laser generative process. Normally, an intermediate machining between the tracks and layers is not necessary.

The primary process parameters laser power, wire feeding rate and welding speed have to be adapted to each other to enable a continuous melt flow of the wire into to the laser induced melt pool. For certain primary parameters, the process stability depends on the heat flow regime during the build-up process. Besides the temperature regulation mentioned above, also interruptions between selected layers may be useful to cool down the material. If necessary, also an active gas cooling of the material can be applied [3].

In Fig. 3 the cross section of a generated structure of the Nickel super alloy INCONEL718 is shown. The solidified structure is defect free and each layer is metallurgically bonded to the other. Through optimization of the process parameters, even the crack-sensitive IN718 structure is crack-free. An optimized build-up strategy allows minimal surface roughness of RZ = 63 µm. A layer thickness of 1.4 mm and a build-up rate of 100 cm^3/h can be achieved with 3.0 kW laser power and 2.0 m/min welding speed. Simultaneous heating of the wire using efficient electric energy (hot-wire deposition) increases significantly the deposition rate up to about 160 cm^3/h [4].

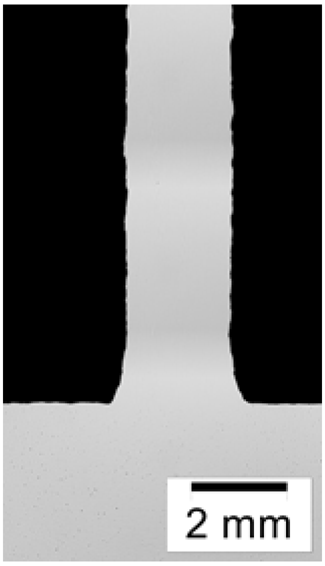

Fig. 3. Cross-section of a laser generated wall of INCONEL718

Standard welding feedstock wires can be used as deposition material. The suitable wire diameters range from about 1.2 mm down to 0.3 mm. Using the fine wires, the best lateral resolution of the generated structures lie in the range of 0.6 mm. Here the deposition rate amounts to 30 cm^3/h.

Figure 4 illustrate two examples of layer-by-layer generated parts. Figure 4a shows a turbine blade out of INCONEL718. The blade's height is 100 mm, and inside it has a hollow structure. The height of the inlet tube of Figure 4b is 85 mm, and it consists of light-weight alloy AlMg5. The height of the single layers is 0.4 mm for the Ni alloy and 0.7 mm for the Al alloy.

Fig. 4. Turbine blade out of INCONEL718 Inlet tube out of AlMg5

4 Summary

The current state of laser wire deposition shows the wide range of potential applications of this new technique. In addition to the well-established powder welding and powder-bed melting techniques, wires represent an advantageous alternative for high-quality laser deposition. A specially developed laser head with coaxial wire supply permits omni-directional welding operation and thus new dimensions in additive manufacturing. Also, equipment for the on-line process regulation is available and can be used for quality management. In particular, the regulation concerns the melt bath's dimensions and temperature on its surface.

As construction material, commercially available welding feedstock wires can be used. The material utilization is always 100 %, the welding process is clean, and the variant of hot-wire cladding advantageously increases productivity and energy efficiency. The generated metal structures are completely dense, as important precondition for a high mechanical strength of the final parts. The surface roughness is typically lower than RZ100 µm, and the model-to-part-accuracy lies in the range of some tenth of a millimetre.

Examples of application are corrosion protection coatings on cylinders, turbine parts of Nickel and Titanium [5] alloys as well as light-weight parts for automobile use.

5 References

1. S. Nowotny (Editor): Laser Cladding with Centric Wire Supply
   ISBN 978-3-8396-0020-7, Published by Fraunhofer Verlag 2009
2. D. Hautmann: Adaptive Laser Welding (in german)
   REPORT, ed. by MTU AeroEngines, Vol. 2, 2010 , pp. 30-33
3. E. Beyer: High-Power Laser Materials Processing
   Proceedings of the 31st International Congress on Applications of Lasers and Electro-Optics, Anaheim, CA, September 23-27, 2012, paper OP2
4. H. Pajukoski, J. Näkki, S. Thieme, J. Tuominen, S. Nowotny, P. Vuoristo: Laser Cladding with Coaxial Wire Feeding
   Proceedings of the 31st International Congress on Applications of Lasers and Electro-Optics, Anaheim, CA, September 23-27, 2012, paper P124
5. E. Brandl, V. Michailov, B. Viehweger, C. Leyens: Deposition of Ti–6Al–4V using laser and wire
   Surface & Coatings Technology 206 (2011) pp. 1120–1129