Lasers in Manufacturing Conference 2015

Hybrid lightweight design by laser additive manufacturing and laser welding processes

Prof.Dr.-Ing. Claus Emmelmann[a], Dipl.-Ing. Frank Beckmann[a]

[a] *Hamburg University of Technology (TUHH - iLAS), Denickestrasse 17, 21073 Hamburg, Germany*

Abstract

This paper deals with the design and production of hybrid components as a combination of laser additive and conventional manufactured segments by laser welding. Hereby the economic and technological limits of the LAM process can be overcome. The study goes into the weldability of the material with the focus on the cast alloy AlSi12 and evaluates static strength of the hybrid connection.

Keywords: Additive Manufacturing; Laser Welding, Hybrid Manufacturing

1. Introduction and motivation

Laser additive manufacturing [LAM] is an innovative production process that offers completely new possibilities of construction because of its high level of design flexibility. Furthermore it provides great potential for function integration and lightweight construction. By means of topology optimization as well as bionic construction principles it is possible to develop mechanical components, which feature the same strength and stiffness, but have a 30 to 70% reduced weight in comparison to conventionally machined parts. [1,2]

Limitations of the 3d Printing technology are the maximum part size due to machine limitations and the current low rate of productivity. Therefore the process is for big parts and high quantities at present still uneconomic. In order to avoid those restrictions it is appropriate to use a welded component design, which either consists of two 3d printed parts or of the combination of a 3d printed and a conventional manufactured section (sheet metal, cast, milled parts, etc.). Figure 1 shows the basic principle of this hybrid approach manufacturing approach.

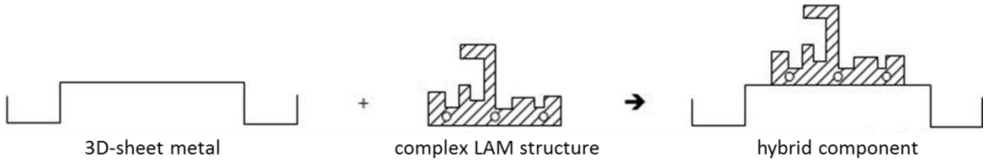

Figure 1: Principle of hybrid component design using the example of the combination of a simple sheet metal base body with a complex functional LAM structure

Due to its low density aluminum is a preferred lightweight material. But especially during the joining of these 3d printed aluminum components by the use of laser welding, challenges defined by process parameters occur, that heavily differ from the welding behavior of conventionally manufactured parts. Chapter 2 points out these phenomena and shows solution by means of a directed adaption of the parameters and pretreatment strategies of the parts. Beside the welding analysis the mechanical properties of the hybrid connection are analyzed in chapter 3.

2. Laser welding of aluminum hybrid components

To join hybrid aluminum components for these investigations laser welding as a highly focused and thus low-distortion welding process is used. It allows to design filigree lightweight structures. To test the welding process for hybrid components various welding specimens from AlSi12 are manufactured in different primary shaping processes. These are firstly produced laser additively with standard parameters on a SLM 250 HL machine and the others are made with the same material in sand casting. The two materials are welded each of the same type as well as a hybrid combination of LAM and cast material. The welding was done by the usage of the same kind of filler wire (AlSi12) and with constant process parameters through the first experiments in order to enable the direct comparison of the process results.

2.1. Porosity in the weld zone in dependence on the primary shaping process

The experiments show despite the same alloys of the used material (AlSi12) a different welding behavior, which is outlined in the shape of the weld seam and in particular in the formation of the pores. Figure 2 shows the welding results of the different material combinations in form of cross sections.

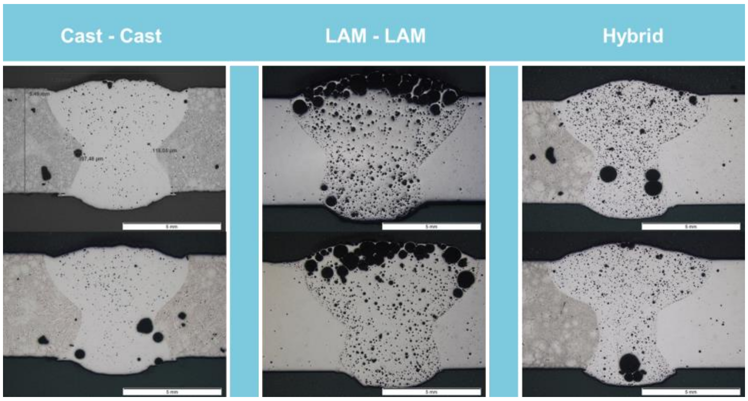

Figure 2: Comparison of the cross sections while using the same welding parameters

The welded cast material in figure 2 shows the formation of individual large pores of up to 800 µm in diameter. Also in the base material single large pores of up to 400 µm are present.

The connection of the LAM base material shows a significantly deviating characteristic of weld seam. Significantly more pores are formed in the lower part of the solidified melt pool. The small pores agglomerate during ascension in the liquid melt pool and are enclosed in large numbers and with diameters of up to 900 microns just before the degassing at the joint surface. This increased pore formation cannot be explained by the porosity of the base material, which is with a relative density of > 97% for the laser additive manufactured material lower than the porosity of the cast material.

The welded connection of the hybrid component, i.e. the combination of cast and LA- material is a mixture of both seam characteristics. It forms as for the cast samples single large pores at the bottom of the connection as well as a large number of small and finely divided pore inclusions on the basis of the generated material.

2.2. Analysis of the material

To explain the different welding behavior with the identical base alloy and the same welding process parameters the laser additive manufactured and cast base material is analysed. The analysis of the material compounds by atomic emission spectroscopy shows no abnormalities. According to table 1, the samples show similar alloy compositions that are within the tolerances according to the alloy specification.

Table 1. Alloy composition of LAM and casted base material

Material	Mn	Fe	Cu	Zn	Ti
LAM - AlSi12	437 mg/kg	1570 mg/kg	< 200 mg/kg	< 200 mg/kg	< 200 mg/kg
Cast material - AlSi12	< 200 mg/kg	1220 mg/kg	466 mg/kg	< 200 mg/kg	622 mg/kg

When looking at the pore formation in laser welding of aluminum, one distinguishes between process pores and hydrogen pores. [3] Since the process was identical in all tests there may be no reason for the differing weldability here, so that the process pores will not be discussed any further at this point. The hydrogen pores evolve by significant solubility leap of the hydrogen during solidification. The bonded hydrogen in the material is excreted during the solidification of the material and forms hydrogen pores in the weld seam. An obvious explanation for the increased weld porosity is thus an increased hydrogen basic salary in the laser additive manufactured samples. Measurements by means of carrier-gas-melt-extraction-analysis refute this thesis. The LAM samples have with 3.43 ppm significantly lower hydrogen content than the cast samples with 6.43 ppm.

2.3. Influence of post-treatment processes on the pore formation

Laser additive manufactured components are usually separated from the building platform by wire-cut EDM and freed of powder residues and optimized in the surface roughness by means of sandblasting. The influences of these post processing techniques on the laser beam welding process and in particular the aforementioned pore formation were analyzed by courtesy of statistical methods. There was no significant effect of the typical component preparation procedures on the pore formation in the laser weld determined. It were untreated LAM sample surfaces (as built), sandblasted and wire-cut EDM sample surfaces examined. An influence of potential powder adhesions, residues of the sandblasting or water from the wire-cut EDM could not be identified.

2.4. Welding process optimization

In basic welding tests the parameters welding speed (2 m/min / 3 m/min) focal position (-1 mm / -2.5 mm) and preheating of the samples (without / 80°) in terms of the influence on the formation of pores during the welding of the laser-generated components were examined using a factorized experimental design. This results in a significant effect regarding the focus position with the optimum at the greater defocusing of -2.5 mm as well as a positive influence when using preheating. The welding speed considered individually has no significant effect, but the interaction of welding speed and preheating. A minimum porosity can be achieved when using preheating, a welding speed of 2 m/min and a large defocussing of 2.5 mm. This can be explained with a larger molten pool due to the low speed and defocusing as well as a lower cooling rate because of the preheating. The melt pool thus remains open longer and allows the pores to rise and degas of the melt.

2.5. Further investigations

In order to forward the optimization of the pore formation during the laser beam welding of aluminum hybrid components, initially the causes of the deviant welding behavior will be exposed in further investigations. Thereby not only the absolute amount of hydrogen in samples will be analyzed but it will be considered spatially resolved to take also possible influences of surface effects, such as an increased oxide formation on the rougher surface, into account. According to Gellert [4] the hydrogen pores are forming during the welding process of aluminum mainly by means of a so-called heterogeneous nucleation. This means, that the formation of pores starts from pre-existing surfaces in the melt pool, such as refractory phases, as well as nitrides and oxides. To clarify a potential reason for the different welding behavior of laser additive manufactured aluminum and casted material in the following studies the number and the distribution of these particles in the raw material will be analyzed using an electron microscope.

On the part of the welding process, further investigations will be carried out to minimize the number and the size of the pores. Thus the from other aluminum applications known approaches of high-frequency beam oscillation and dual focus technology can be transferred to this hybrid application.

3. Mechanical properties

In order to use hybrid components in lightweight construction for mechanically stressed parts it is essential to know the strength of the hybrid connection. Based on the identical samples from chapter 2 tensile specimens were created. Here five combinations were created: Cast material (not welded), Laser additive manufactures material (not welded), Cast material welded, LAM welded and Hybrid samples from sand casting and LAM.

The later welded raw samples were processed by milling to tensile specimens according to DIN 50125. Here the seam surfaces as well as the seam root were removed to examine only the material influences on the strength and exclude geometrical surface defects.

Figure 3 shows the results of the tensile tests. Not welded LAM samples show a twice as high tensile strength than the sand-cast samples and also the requirement of the aluminum key. The consequence of the layered structure of the material is a fine-grained microstructure that is superior to the classical cast material and rolled material. The casting material is with an average strength of 142 N/mm^2 slightly below the aluminum key. This is justified by the manufacturing process, where 6 mm thick flat specimens were manufactured in the sand casting process. In this method it is not possible to achieve the optimum material properties and densities, as if it would be feasible in an industrial die cast process with the same material.

The failing of the samples starts for all cast samples from the up to 400 µm sized pores in the base material. The same behavior is reflected in the welded cast samples where the failure also starts at the pores of the base material. The weld and the associated heat-affected zone has a higher strength than the base material. However for the welded LAM samples starts the failing on the basis of the significant pores (up to 900 µm in diameter) in the laser weld seam. With a tensile strength from an average of 222 N/mm² these samples are below the base material, but also above the cast samples and the requirements of the aluminum key. With the hybrid samples from cast and LAM material shows the expected effect that the samples fail in the base material of the cast segment.

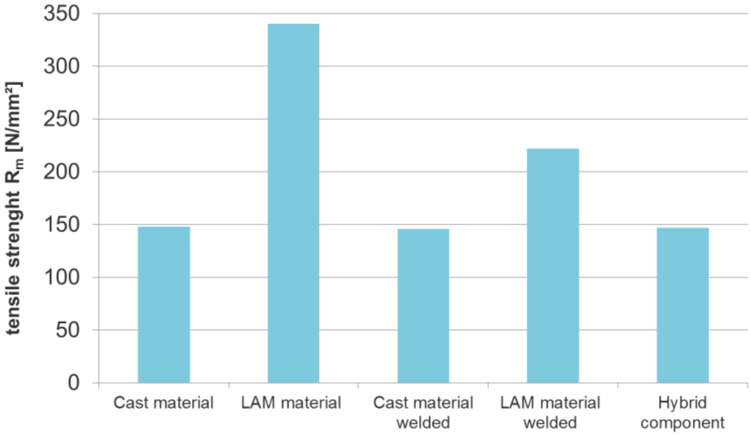

Figure 3: tensile strength of the hybrid components

The results of the static tensile test are consistent with the hardness of the material. Figure 4 shows the Vickers hardness profile of a hybrid specimen. It is clear, that the highest hardness values are present in the additive manufactured base material. It decreases over the heat-affected zone up to the molten weld, run there constantly and reaches the lowest values in the cast base material.

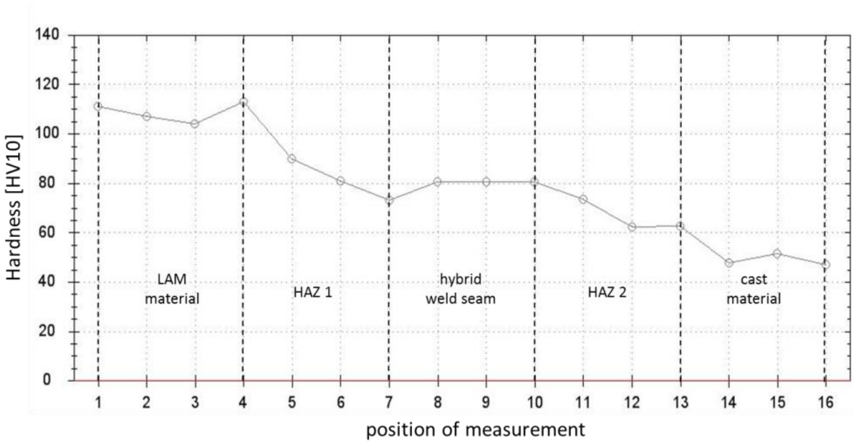

Figure 4: Hardness plot across the weld seam of a hybrid manufactured specimen

For the hybrid design statically loaded components can thus be deduced that the strength of thecasted base material determines the strength of the entire hybrid part.

4. Conclusion:

The basic weldability of hybrid aluminum (AlSi12) components as a combination of LAM and conventional manufactured segments has been shown in principle. Here was a different welding behavior, particularly a widely varying pore formation in the weld seam of LAM material detected and parameter approaches shown, to reduce them.

Static tensile tests show that in the investigated hybrids, the cast base material has the lowest strength and thus leads to failure of the component. The weld seam reduces the tensile strength of the LAM part joined with the same material, but not the strength of the combination of the LAM and cast material. For the hybrid design statically loaded components can thus be deduced that the strength of the casted base material determines the strength of the entire hybrid part.

References

1. Emmelmann, C. et al.: Leichtbaupotential durch das Lasergenerieren bionischer Strukturen, in: Proceedings der Rapid.Tech 2010 – Fach-messe und Anwendertagung für Rapid-Technologie, Erfurt, 2010.
2. Emmelmann, C. et al.: Manufacturing for Design – Laseradditive Fertigung ermöglicht neuartige Funktionsbauteile; Industrie Management, 2013
3. Winkler, R.: Porenbildung beim Laserstrahlschweißen von Aluminium-Druckguss, München, 2004
4. Gellert, M. Wasserstoffporenbildung beim Laserstrahlschweißen von Aluminium, Aachen, 1998