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Optimization of the weldability of laser additive manufactured aluminum by means of hydrogen minimization in the component and welding parameter optimization

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

[a]*Fraunhofer IAPT, Am Schleusengraben 14, 21029 Hamburg, Germany*

Abstract

Laser additive manufactured [LAM] aluminum components are increasingly used, but have a critically high seam porosity after laser welding, which does not meet the limits of the standard without further action. This paper presents measures to reduce seam porosity in laser beam welding of LAM components. Here, welding parameters such as the welding speed and the use of the double-focus technique are analyzed. In addition, influences of LAM component production, in particular the influence of new powder vs. recycled material, as well as the influence of space heating are investigated.

Keywords: Additive manufacturing; laser welding

1. Motivation and problem definition

Aluminum components manufactured using laser additive manufacturing are increasingly used in the field of prototypes but also for serial applications. In various fields of application, this requires joining technology for integration of the components in overall structures. Examples are 3D-printed hybrid structures as the innovative chassis concept "Next Generation Spaceframe 2.0".

Investigations of the Institute of Laser and System Technology [iLAS] of the Hamburg University of Technology, the university partner institute of the Fraunhofer Institute of Additive Production Technologies [IAPT] have shown, that the fusion welding of additive manufactured aluminum components leads to a strongly increased pore formation in the weld seam compared to conventionally produced material of the same alloy. The focus of these investigations is on the laser based welding process, which is characterized by low-warpage and is an easily automatable welding processes with a slim weld seam ideal for the joining of filigree additive components. Figure 1 shows the comparison of cross sections of laser welded AlSi12 produced by sand casting and laser beam melting with the high porosity of the LAM-weld seam.

* Corresponding author. Tel.: +49-176-148-401-25;
E-mail address: frank.beckmann@iapt.fraunhofer.de .

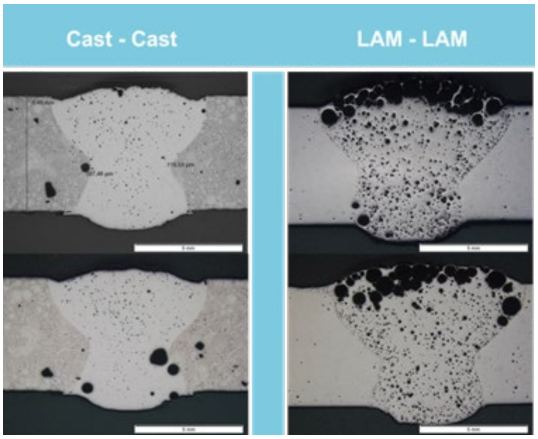

Fig. 1. Comparison of weld seam porosity (a) Cast material (b) Laser Additive Manufactured

1.1. Influence analysis and methodical procedure

A significantly increased pore formation in laser beam welding has been found in all of the typical aluminum alloys used in additive manufacturing, i.e. AlSi10Mg, AlSi12, Scalmalloy and other special alloys. This underlines the results of previous analyzes that it is not the chemical alloy composition that causes the increased pore formation, but the increased hydrogen content of the components. A solubility jump of the hydrogen during the solidification of the melt leads to the fact that this increased hydrogen content can not be further bound in the microstructure but outgasses in the form of pores in the weld and thus produces the pores. The hydrogen porosity is also observed during welding of conventional aluminum components, but occurs there in a moderate form.

The cause of the increased hydrogen content of the additively manufactured components is presumably the powder and its processing from powder atomization to the finished AM component. In the various steps of gas atomization, packaging, and then repeated with each build job steps of filling the powder into the machine, the print job execution, the external sieving of the powder, as well as the re-feeding into the machine the powder is in multiple contact with the ambient air. Since the powder has a much larger surface than a conventional compact component or a cast melt, it offers the possibility of moisture absorption from the environment. This moisture and the hydrogen already dissolved in the powder can not be completely eliminated in the additive manufacturing process. Comparative hydrogen measurements show, that the hydrogen content in the AM component is seven times higher than in the cast material.

There are now two solution paths to optimize the welding results. 1. The optimization of the welding process in order to minimize pore formation in the melt or to support the degassing of hydrogen pores via adapted welding strategies. In various studies of the iLAS, the following influencing factors have already been investigated: Beam oscillation to influence the melt pool geometry and the melt pool dynamics, classic welding parameters such as the welding speed, the defocusing, the inert gas type and quantity as well as the component preheating. Measures, which enlarge the melting bath or keep it open for a longer time and thus give the hydrogen time to outgas, have proved to be positive. Positive were a slow welding speed, a defocusing and a preheating of the material. Based on this, further influences such as the double-focus technique and a more detailed study of the influence of the welding speed are carried out in these investigations. Gref and Hohenberger show that the welding process can be calmed down by use of the multi

Focus technique, thus optimizing weld quality. In this study, it should be analyzed whether the use of double-focus optic can also have a positive influence on the seam porosity. The formation of the laser spots transversely or longitudinally to the feed direction, both the cooling of the melt and the width of the molten bath can be influenced.

The second solution path aims at a hydrogen minimization of the laser-additive-produced component. Thus, the identified cause of pore formation should be reduced even before the actual welding process. Preliminary work by the IAPT and Weingarten on successful methods of hydrogen minimization by means of powder drying before and during the laser additive manufacturing process is already available. Based on this, the following parameters are examined in these investigations:

- The influence of new powder compared to recycled powder.
- The influence of the 200 ° C build plate heating.

In order not to mix the influences of the various measures, these are carried out independently of each other. The welding tests are carried out on untreated SLM test components and to determine the influence of the LAM manufacturing measures, welding tests are carried out using standard welding parameters. In all experiments, a butt joint is welded with the aim of achieving a complete penetration.

1.2. Equipment and experimental evaluation

Manufacturing of specimens: The samples to be welded are manufactured with the machines SLM 250 and EOS M290. Standard process parameters and the materials AlSi10Mg and AlSi12 are used. There is no separate heat treatment. The samples of geometry 3 mm x 25 mm 60 mm and 5 mm x 25 mm x 60 mm are built standing on the small surface in order to maximize the platform utilization. The samples are built on support structures to easily separate them from the build platform.

Welding equipment: Two laser welding systems from Trumpf are used. 1. The TruLaser Robot 5020 robot cell with a TruDisk 6001 disk laser, a 300 µm process fiber and a BEO 70 laser welding optics with a 1:1 aspect ratio. This results in a focus diameter of 300 microns with a focal length of 200 mm. The second welding system is a TruLaser Cell 7006 with a BEO70 optics with bifocal module and also 1:1 aspect ratio and 200 mm focal length. In this system a 8 KW TruDisc 8001 disk laser is used.

Experimental evaluation: The welding results are evaluated by creating cross-sections at several positions of the weld. By means of a microscope, the ratio of the pore area to the total area of the weld seam is measured and evaluated. Since the process results have a high mean variation, 3 or 5 seams are welded per parameter set and these are evaluated with 2 or 3 cross sections per seam. This results in 9 or 10 cross sections per experiment.

2. Welding parameter optimization

First, the experiments and their results for welding parameter optimization are shown.

2.1. Influence of the welding speed:

The aim of the investigation is to analyse the influence of the welding speed in detail and to underpin the tendencies of previous investigations. Welding is done with the TruLaser Robot 5020 as a butt joint configuration on 3 mm thick ALSi12 material. The laser power is always adjusted so that full penetration of the 3 mm material is achieved. The Laser power thus varies between 3.25 and 4.7 KW. The laser is defocused -1.5 mm into the material and 20 l/min Lasgon shielding gas is used. Depending on the speed, 5 seams with 2 cross sections each are created.

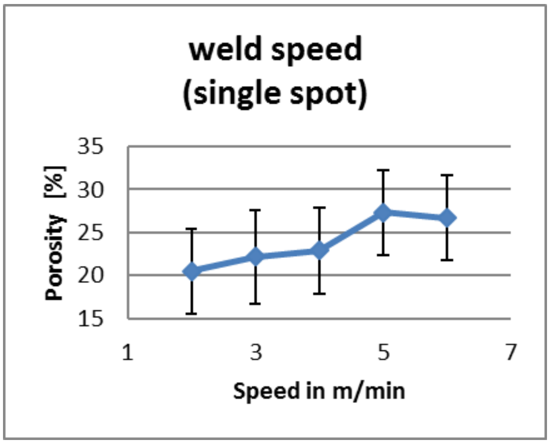

Fig. 2. Weld seam porosity as a function of the welding speed

The results of the preliminary investigations are confirmed. A slow welding speed reduces the porosity within the weld seam. It keeps the melt pool open for a longer time, allowing the pores to degas from the weld.

2.2. Double spot technique

In order to determine the influence of the double-spot technique on the seam propensity, test series are carried out with variation of the welding speed and the formation of the laser spots. According to Figure 3, the tandem formation was investigated, which leads to a longer melt pool, as well as transverse formation, which leads to a wider melt pool. The distance between the two 100 µm spots is 0.3 m. The samples in these examinations consist of 5 mm thick AlSi12 built on the SLM 250. The focal position is -2 mm in the material and 20 l/min argon are used as protective gas. For each parameter 3 seams á 3 cross sections are generated.

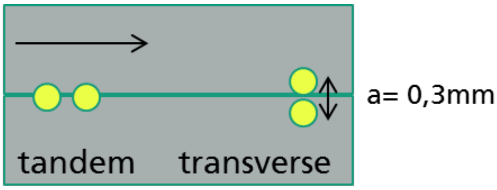

Fig. 3. Representation of the focus formation in double spot welding

When examining the welding speed, the same result can be seen, which could already be determined with the single spot. A slower welding speed leads to a lower seam porosity. The investigations were carried out in tandem arrangement.

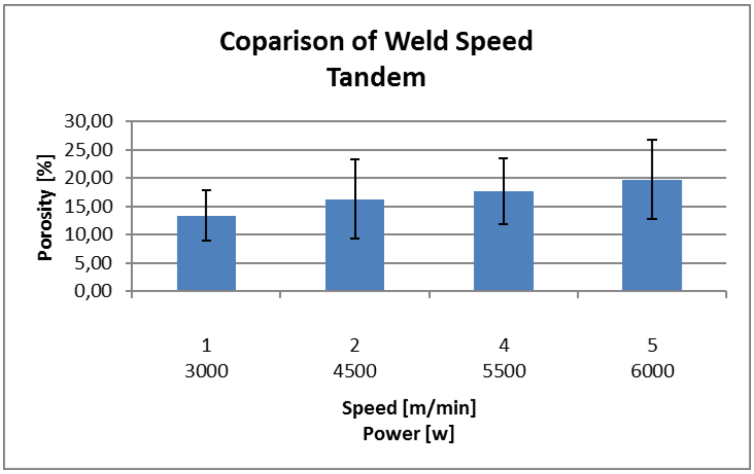

Fig. 4. Weld Seam porosity at bifocal welding depending on the welding speed

In the following, the by changing the formation of the laser spots it is analyzed whether a wider or a longer melt pool is beneficial. The results show, that the transversal formation leads to slightly smaller seam porosities. However, due to the high mean variation this effect can not be considered significant despite 9 Cross sections are analyzed per parameter. Furthermore, it shows that the reference welds with comparable parameters, but only one laser spot, have lower porosities than the double spot weld seams. Thus, although the double-spot technique shows a positive effect on the seam surfaces, it does not reduce the porosity in the cross section.

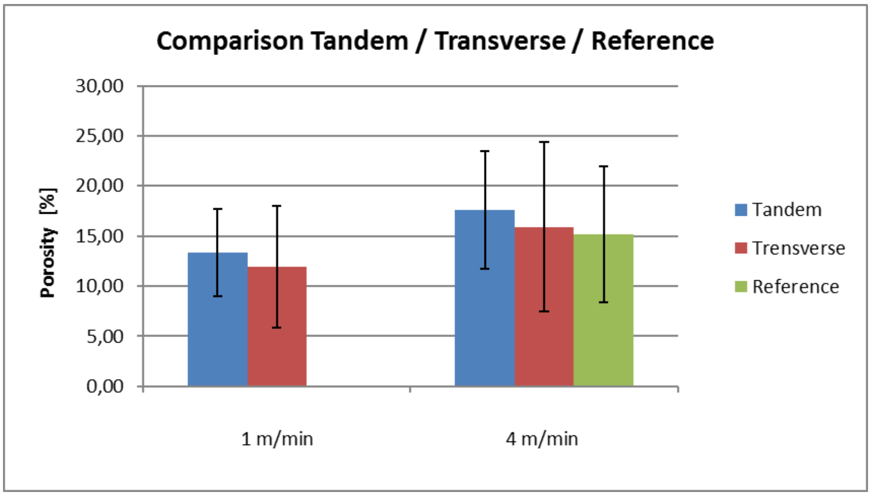

Fig. 5. Seam porosity in bifocal welding as a function of the focus formation

3. influencing factors of laser additive manufacturing process

In order to counteract the actual cause of porosity, the hydrogen content of the LAM material, the influence of the powder quality and the platform heating within the AM process is examined in this section.

3.1. New powder vs. recycled material:

In this comparison, the first build job is printed with new powder directly from the manufacturer. This was delivered in the usual plastic containers incl. dry bag and filled directly into the machine. This is compared with samples printed from already used and recycled powders. As part of the build jobs, this has contact with the ambient air both during filling of the machine, as well as the unpacking of the build jobs, the filling into the sieving station as well as the intermediate storage during the use of other materials. In this case, moisture can be absorbed by the powder. Both welding samples are built with identical LAM parameters on the EOS M290 machine and then joined with the TruLaser Robot welding system and likewise identical welding parameters. In this case, a significant difference in the weld porosity is determined according to the following Figure 6. For used powder, the seam porosity is higher by a factor of 2.4. It is therefore always advisable to work with fresh powder or to take measures so that the powder quality remains stable in the recycling process. For this purpose, a completely closed powder circuit would be required, which is often not realized in the application or can not be realized due to the plant design.

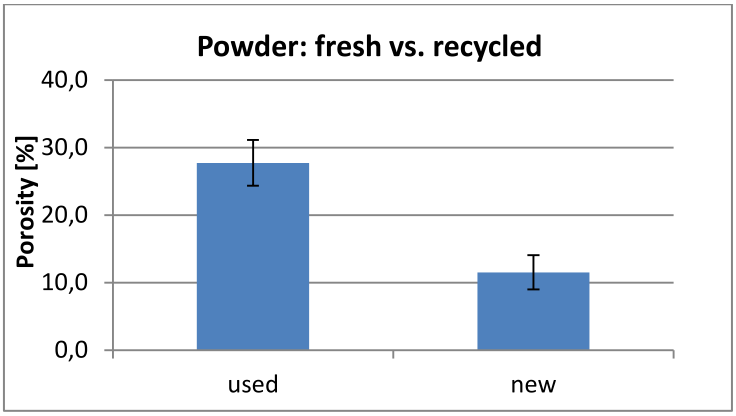

Fig. 6. Weld Seam porosity depending on powder quality: used vs. fresh

3.2. Preheating of build plate:

In various preliminary investigations, powder drying measures were investigated outside of the LAM machine. These measures require additional effort and usually involve handling steps under ambient atmosphere, so that it can come to a renewed contamination with the ambient air. The easiest step to heat the powder and allow moisture to evaporate from its surface is to use the usual platform heating within the LAM machines. This preheating is usually not used for aluminum printing, since this material does not tend to critical residual stresses. However, AlSi10Mg samples with and without space heating are built in the EOS M290 and then welded. It shows a positive influence of the preheating, so that the use of the heating for components, which are then to be welded, is recommended.

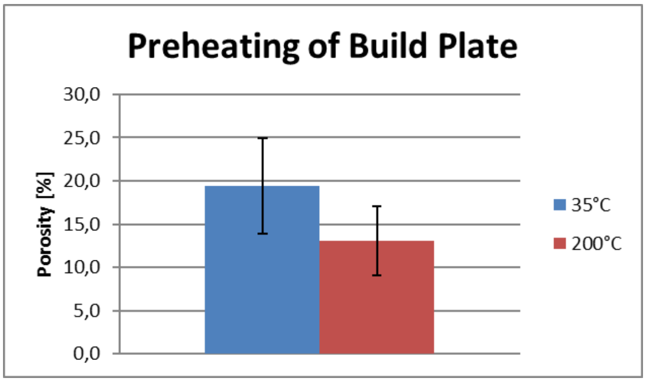

Fig. 7. Weld seam porosity depending on Preheating of LAM-build plate

4. Summary

In these investigations, measures for the reduction of the seam porosity during the laser beam welding of additively produced components were tested. This includes strategies for welding process optimization as well as strategies to reduce the hydrogen content within the additive manufactured components. The welding process analysis shows, that the use of the double spot technology has no positive influence on the seam porosity. The choice of an optimal, low welding speed, however, shows a positive influence and confirms existing preliminary investigations.

A big influence is the use of fresh powder. This shows a significantly lower weld seam porosity than recycled material. Likewise positive is the use of platform heating.

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