STUDY OF FATIGUE LOADING OF THE SLM AND CAST MATERIAL BY ACOUSTIC EMISSION METHOD

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Abstract

Presented paper compares fatigue behaviour of alloy AlSi9Cu3 produced by gravity casting and Selective Laser Melting (SLM). SLM is one of the additive manufacturing methods. It allows a production of metal parts with complicated shape in relatively short time and without big material waste. However the quality of final material could be worse than conventionally produced one (e.g. moulded or extruded).

Acoustic emission (AE) method is used to obtain detailed informations about fatigue behaviour. Compared to previous work, the new methods of AE signal analysis is used. This method provides a more detailed AE signal analysis, in addition to number of count and events, also takes into account rise time and amplitude of the events. So we do not get only a ratio of fatigue stages but also an idea of microstructure changes during cyclical loading.

Main aims of presented study are to compare endurance limit of cast and SLM aluminum alloy using standard S-N curves and analyse the fatigue processes using AE method. Both materials were tested in as-cast resp. as-built condition without any heat treatment. All samples were subjected to fatigue bending tests in high-cycle regime. Result shows that the endurance limit of the SLM material is better than the cast material with a similar chemical composition. AE signal analysis shows different ratio of fatigue stages and indicate a different mechanism of crack initiation and grow.

Keywords: Acoustic emission, fatigue, selective laser melting, aluminium alloy

1. INTRODUCTION

Additive manufacturing (AM) is one of the most growing fields of production technologies today. Selective laser melting (SLM) is one of those technologies that allow the production of metal parts. SLM technology principle is on adding of thin material layers of metal powder and their connecting by a focused laser beam. As it is new technology, the range of manufactured materials is constantly expanded. The quality of any new material must be compared with conventionally produced. It was proved that not every alloy is suitable for SLM technology [1].

Previous works showed that foundry aluminium (Al) alloy with chemical composition near eutectic. Paper of Brandl et al. [2] showed that it is possible to achieve fatigue limit comparable with conventionally produced materials. The final quality of the material does not depend on the axis position of the samples on the base plate, but it could be significantly improved by T6 heat treatment.

Bagherifard et al. [3] reached more or less same results in their work. Beside heat treatment, the effect of sand blasting and shot peening in order to decrease residual stress was examined. The best result was achieved with combination of heat treatment and sand blasting. Fractography analysis showed that main crack was initiated by connection of multiple microcracks from the surface or sub-surface defects.

Defects in SLM materials are descripted in work of Liu et al. [4]. Authors studied alloy Ti6Al4V. Basically three types of defects were with common designation “Lack of Fusion” (LOF). The first type was indicated as a clean cavity, the second cavity with unmelted powder particles and the third long shaped cavity with unmelted particles.

All authors agree that fatigue cracks are initiated on the surface or sub-surface production defects.

Presented paper follows our previous study [1]. SLM materials were subjected to fatigue bending tests with acoustic emission records and results were compared with conventionally produced materials (extruded). Results showed that fatigue limit of SLM material is much worse than extruded, however, in case of copper alloy, the difference were less significant. Acoustic emission records showed three fatigue stages: pre-initiation, initiation and post-initiation. The difference between SLM and extruded material was observed in ration of those stages. Base on this result we decided to continue with foundry aluminium alloy AlSi9Cu3.

2. MATERIALS AND METHODS

2.1. Materials

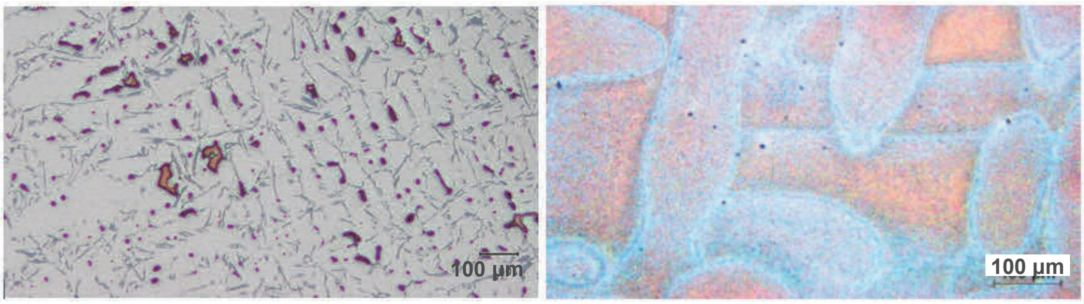
The used alloy is AlSi9Cu3. This kind of alloys is commonly used for casting and its chemical composition is close to the eutectic. The reference material was produce by standard gravity casting without any heat treatment. Tensile strength of SLM material was 485 MPa and 177 MPa in case of cast material.

Optimal SLM production parameters were determined in base of the best internal porosity, this process is described in work [5]. Final production parameters are showed in the **Table 1**. Position of SLM samples axes was parallel to base plate.

Table 1 Final optimal SLM production parameters [5]

Laser power	Laser speed	Hatch distance	Beam diameter
400 W	1300 mm/s	150 µm	82 µm

Microstructure of both materials is shown on the **Figure 1**. The cast material (**Figure 1a**) is characterized by inhomogeneous microstructure with sharp intermetallic phases. Microstructure of SLM material (**Figure 1b**) is also inhomogeneous, but we can see only boundaries of production layers and rounded pores.



(a) (b)

Figure 1 Microstructure of cast material (a) and SLM material [5] (b)

Both materials were tested in as-built (resp. as-cast condition). Tensile strength of SLM material was 485 MPa and 177 MPa in case of cast material.

2.2. Fatigue testing

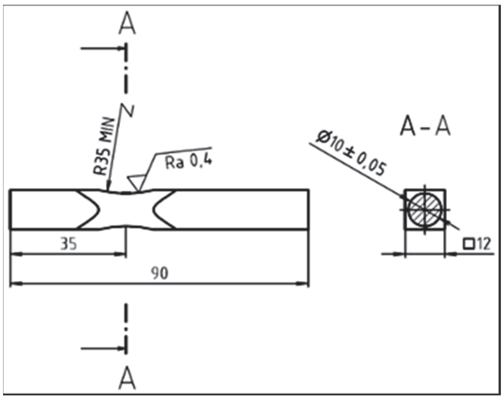
All specimens were machined according the **Figure 2a**. From SLM material was produced 11 specimens and from reference (cast) material 12 specimens. Fatigue bending test were carried out by electro-resonance machine RUMUL Cracktronic 8204 at room temperature. Fatigue cycle was sinusoidal with stress ration

R = -1. Fatigue testing was supplemented with fractography analysis using scanning electron microscopy (SEM).

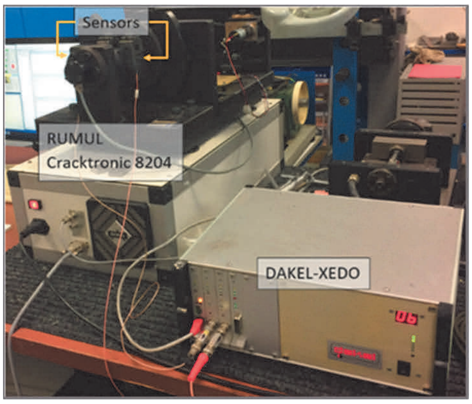
2.3. Acoustic emission

Acoustic emission (AE) signal was detected by Dakel-XEDO monitoring systems using two piezoelectric DAKEL MIDI sensors with 35 dB preamplifier. XEDO system allows 12-bit synchronous sampling with sampling frequency 2MHz and continuous saving data to a computer. The sensor was clamped on each end of the specimens by Loctide glue. The measuring station is shown on the **Figure 2b**.

For postprocessing and data analysis was used new system Dakel-ZEDO that allows to get more information about AE signal and filtration of important AE response.



(a)



(b)

Figure 2 Geometry of testing specimen (a) and measuring station (b)

3. RESULTS

3.1. Fatigue

Results of bending fatigue tests of both materials were compared using S-N curves in log-log coordinates (**Figure 3**). SLM material has slightly better fatigue limit than cast material. It is probably connected with sharp intermetallic phases in the cast microstructure that are not visible in the SLM material microstructure. However the layers borders are not favourable for fatigue resistance. It is not possible to get relevant fatigue limit as the amount of tested samples is not representative. Estimate is around 120 MPa in case of SLM material and 90 MPa in case of cast material.

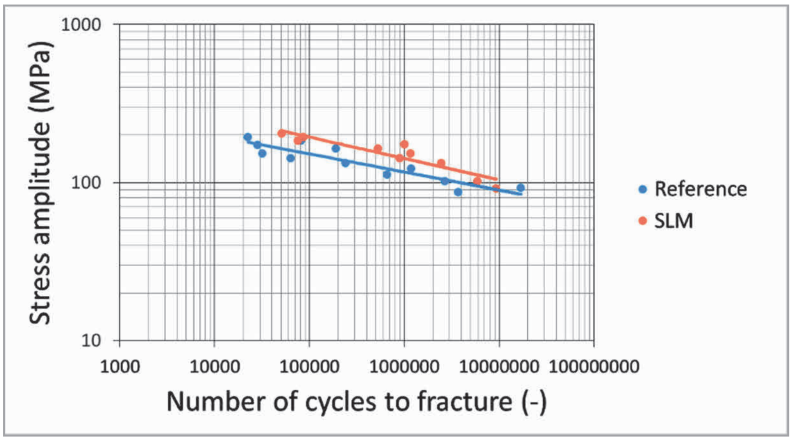


Figure 3 S-N curves of SLM and reference material

3.2. Acoustic emission

Overall AE records are shown on the **Figures 4** and **5**. Three fatigue stages are recognizable in case of both materials. Stage A: pre-initiation stage is characterized by significant AE activity caused by microstructure changes. Stage B: initiation stage is typical with low AE activity, the crack is initiated here. Stage C: post-initiation stage is characterized by very high AE activity caused by crack growth.

Ratio of all stages is more or less the same in both materials, but there is clear difference in overall AE activity. The differences between individual stages are more visible in case of cast than SLM material. While in case of cast material the amount of AE counts and number of hits are changing for every stage, in case of SLM material the change is visible mainly in record of root mean square (RMS - average AE energy). The increase of number of hits in last stage (C) is not so significant in case of SLM, as in the case cast material. It suggest a different mechanism of crack initiation and growth.

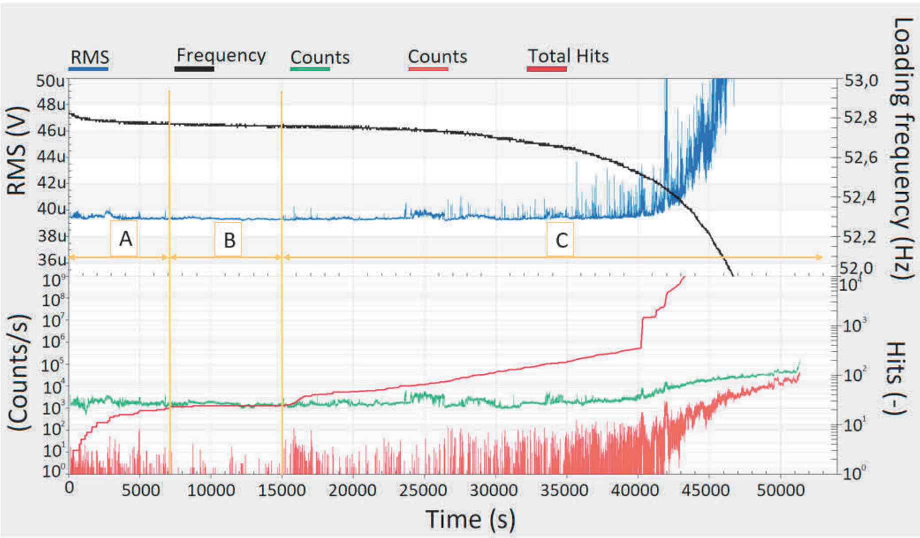


Figure 4 AE record of cast material

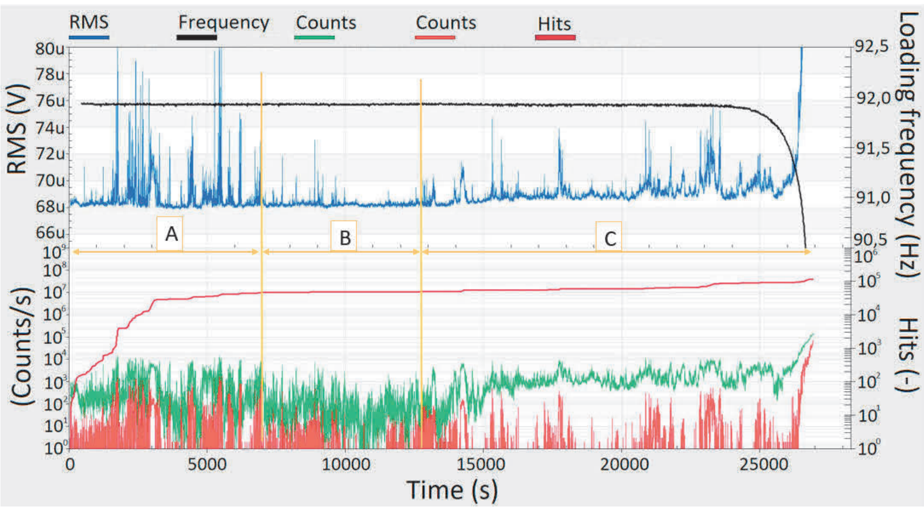


Figure 5 AE record of SLM material

Figure 6 shows detail look of AE hits parameters maximum amplitude and duration for stage A and B, stage C is not subject of this study. The difference is clearly visible. Beside the amount of hits, in case of SLM were detected significantly more hits than in case of cast material, the duration of hits is different, maximal amplitude is same in case of both material as well as in case of both stages. AE hits duration of SLM material fatigue stage A is approximately between $5x10^4$ and $1x10^6$ ns, in case of reference material it is between $1x10^4$ and $5x10^5$ ns. AE hits duration of SLM material fatigue stage B in approximately between $5x10^4$ and $77x10^4$ ns, in case of reference material it is between $15x10^4$ and $37x10^4$ ns. It is again suggest a different mechanism of crack initiation.

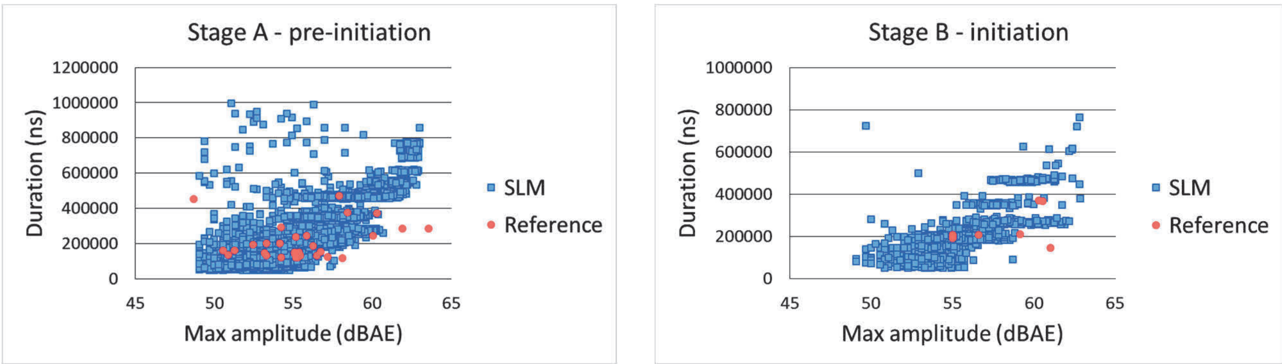


Figure 6 AE hits parameters: Max amplitude (dBAE) vs. duration (ns) in stage A and B

3.3. Fractography

Fatigue bending test and AE measurement were supplemented by fractography analysis shown on the **Figure 7.** Crack origin is marked by the red ring. It is located in sub-surface defect (pore). The main crack spreads through the linking of micro-cracks between the defects and along the building layers borders.

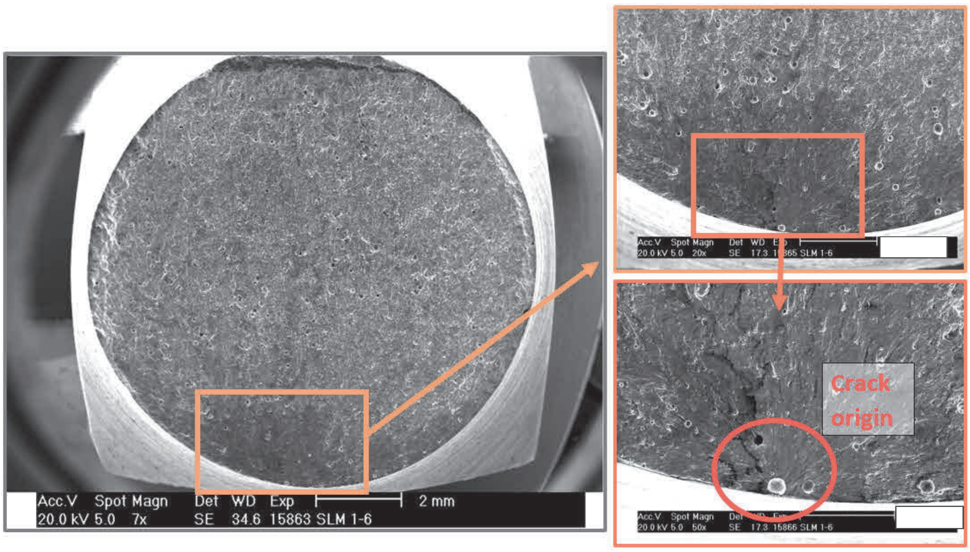


Figure 7 Crack surface of SLM material with detail of crack origin

4. CONCLUSION

Presented study showed results of fatigue testing of SLM and cast alloy AlSi9Cu3 supplemented by AE measurement and fractography analysis. The results of both materials were compared to determine whether the cast material could replace SLM material. Both materials were tested in as-cast resp. as-built condition.

Results of fatigue bending test were compared using standard S-N curves in log-log coordinates. Fatigue limit of SLM material is slightly better than cast material. It is caused by inhomogeneous microstructure of cast material with sharp phases that ware not observed in microstructure of SLM material.

AE records show that in both material is possible to observe three fatigue stages: pre-initiation (A), initiation (B) and post-initiation (C). The ratio of individual stages is more or less the same in case of both materials, but overall AE activity is different. Further AE analysis showed difference in duration of AE hits not only between stage A and B, but also between SLM and cast material. It suggests different mechanism of crack initiation.

Fractrography analysis showed that crack origin is located in the subsurface defect and the main crack spreads through the linking of micro-cracks between the defects and along the building layers borders. The analysis connects AE signal with actual changes in material structure.

Results indicates that cast material could be replaced by SLM material as the fatigue limit is similar, but it must be keep in mind that fatigue behaviour (mechanism of crack initiation and propagation) is different. Further sudies focused on testing of same materials after heat treatment and deeper analysis of AE signal are needed.

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