The Influence of Surface Roughness on Laser Beam Welding of Aluminium Alloys

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Abstract: A laser beam is the light that is subject to the laws of physics. Surface roughness can cause that the light can be reflected in different angles. Therefore, the surface roughness may influence the amount of light to be reflected so the power of the laser could be lowered. Present paper analyses the influence of different surface roughness on porosity and geometry of weld joint using design of experiment. Surface roughness monitored during the experiment was in the range from $Ra_{0.8}$ to $Ra_{15}$ achieved and by machining on aluminium-lithium alloy AW2099. In order to keep the same condition for welding the bead on plate welds were realised. Porosity was analysed using computer tomography. Surface roughness proved to have minor influence on porosity as well as the shape of the weld joint.

Keywords: computed tomography; laser beam welding; porosity; surface roughness

1 INTRODUCTION

Nowadays the aluminium alloys are considered one of the best and mostly used construction material in the industry. They replace steels in many applications because of their specific mechanical and corrosion resistance properties as well as low density. As a construction material aluminium alloys must have good weldability especially for progressive welding technologies that can be applied in mass production. One of these technologies is laser beam welding, where porosity of weld metal is a very common problem.

Authors usually agree on the necessity of removal of oxidic layer as a source of porosity, the other ones refer to technology modifications in order to lower the porosity in weld metal. Standard ways to remove the oxides are mechanical techniques using abrasives, or machining, however there is a risk to impress the inclusions coming from sandpaper into the surface. More innovative approach is to use the laser beam to clean the surface prior to welding. According to results from Zhou at al. [1], the laser cleaning pre-treatment can effectively improve the quality of the surface formation of the aluminium alloy weld (Fig. 1). Laser cleaning in air/argon can greatly reduce the weld seam porosity of the aluminium alloy. The weld seam porosity of the aluminium alloy after laser cleaning in argon is the lowest [1].

Most recommendations related to technology modifications rely on laser beam oscillation with very high frequency what creates wider molten pool and brings higher stability to welding process. Negative effect of beam oscillation is humping (Fig. 2) on the weld joint surface. The porosity lower than 2% (Fig. 3) was achieved by 200 Hz oscillation on diameters bigger than 2 mm (circular oscillation). The biggest issue in using the oscillation is the loss of the penetration depth and thus much more output power to get the original penetration from single pass weld is required [2, 3].

![Figure 1: Top view of laser beam weld on laser cleaned surface [1]](image1)

![Figure 2: Longitudinal section view with humping [2]](image2)

![Figure 3: Top view of laser beam weld on laser cleaned surface [3]](image3)

![Figure 4: The behaviour of keyhole with no beam oscillation [4]](image4)

Liu at al. used ultrasonic power to reduce the oxidation. They concluded that the increase of ultrasonic power leads to lowering of porosity. Their results showed increased tensile strength of samples with increase of ultrasonic power as well as shifting the tensile fracture from weld metal to heat affected zone [5].
Han at al. in their research concluded that fatigue strength was reduced from 113 MPa to 56 MPa when the porosity rate increased from 0% to 8.9%, and the porosity position had little effect on it. The fracture crack initiated in the weld surface when there was no porosity in the joint, and the fracture cracks occurred near the porosity edges when the porosities appeared in the weld seam, particularly near the larger porosity [6].

Porosity in aluminium alloys is still a big topic and many people underestimate the surface cleaning. Proper cleaning can influence the mechanical properties because of lack of impurities and oxides in weld metal caused by porosity coming mostly from grease and moisture that is burnt in arc during the welding process [7, 8].

The influence of surface roughness on meltpool dimensions of stainless steel and aluminium during CO₂ laser beam processing was investigated by Obeidi et al. [9]. Their results revealed that the increased surface roughness led to considerable increase of the meltpool due to increased laser beam absorption. The observed correlation between the dimensions of the meltpool and the surface roughness was almost linear [9]. Sokolov et al. found that surface edge roughness at laser beam power more than 10 kW had a significant influence on penetration depth of butt-joint laser beam welding of structural steel [10]. The maximum penetration depth was achieved at $Ra$ roughness of 6.3 $\mu m$ within the range from $Ra = 1.6$ to $8 \mu m$ [10].

The aim of this paper was to study whether the surface roughness has influence on the weld joint porosity and to find out whether surface cleaning by machining can replace the effective, but expensive surface cleaning by a laser beam.

2 METHODS

An aluminium-lithium alloy AW2099 was welded in the form of a sheet with a thickness of 3 mm in the experiment. The chemical composition of AW2099 is shown in Tab. 1.

Prior to the welding process, the surface of the material was milled at 12 locations with different milling parameters to achieve different levels of roughness. Selected geometrical characteristics of surfaces ($Ra$, $Rq$, $Rz$) were determined on milled surfaces (Tab. 2). The milling depth was constantly 0.5 mm. The resulting thickness of the welded material after the milling process was 2.5 mm. The milled material with the designation of the individual samples is shown in Fig. 5.

Table 1 Typical chemical composition of AW2099 (Smiths metals centre, 2018)

|        | Cu | Li | Zn | Mg | Mn | Zr | Ti | Al |
|--------|----|----|----|----|----|----|----|----|
| Min    | 2.4| 1.6| 0.4| 0.1| 0.1| 0.05| 0  | Bal.|
| Max    | 3.0| 2.0| 1.0| 0.5| 0.12| 0.1| 0.1| Bal.|

Surface roughness was measured using Mitutoyo SJ-210 device (Fig. 6).

After roughness measurement 6 machined and 1 brushed were selected as some roughness obtained by machining was very similar. Based on resulting roughness, samples 0, 1, 2, 3, 4, 5, 12 were further analysed.

Tab. 2 describes the parameters for machining and obtained values of roughness. Fig. 7 documents the welding setup using self-designed welding jig capable of shielding the weld root during welding. Argon was used as a shielding gas covering the surface and helium for root because of their density and potentiality to escape from the molten pool.

Weld joint samples were cut out for computer tomography. Same dimensions of all samples were used in order to get the same perspective on porosity of the same representative length. Cutting was realised on manual abrasive cutter with water cooling from Buehler manufacturer.

Table 2 Parameters of milling and resulting roughness

| Sample | $a_p$ / mm | $v_c$ / m min⁻¹ | $n$ / ot min⁻¹ | $f_z$ / mm | $v_f$ / mm min⁻¹ | $Ra$ / $\mu m$ | $Rq$ / $\mu m$ | $Rz$ / $\mu m$ |
|--------|-------------|------------------|----------------|-------------|------------------|----------------|----------------|----------------|
| 1      | 0.5         | 500              | 7958           | 0.01        | 318              | 0.752          | 0.894          | 4.121          |
| 2      | 0.5         | 500              | 7958           | 0.1         | 318              | 5.926          | 6.981          | 26.037         |
| 3      | 0.5         | 500              | 7958           | 0.13        | 4775             | 6.922          | 8.067          | 30.741         |
| 4      | 0.5         | 500              | 7958           | 0.2         | 6366             | 9.124          | 10.837         | 42.128         |
| 5      | 0.5         | 500              | 7958           | 0.05        | 1592             | 5.365          | 4.629          | 19.00          |
| 6      | 0.5         | 500              | 7958           | 0.083       | 2642             | 5.558          | 6.897          | 25.358         |
| 7      | 0.5         | 500              | 7958           | 0.083       | 2642             | 8.812          | 10.437         | 36.426         |
| 8      | 0.5         | 500              | 7958           | 0.045       | 1432             | 5.689          | 6.460          | 22.105         |
| 9      | 0.5         | 500              | 7958           | 0.04        | 1273             | 5.093          | 5.780          | 20.083         |
| 10     | 0.5        | 500              | 7958           | 0.22        | 7003             | 11.514         | 14.957         | 61.706         |
| 11     | 0.5        | 500              | 7958           | 0.24        | 7640             | 10.883         | 13.495         | 54.131         |
| 12     | 0.5        | 500              | 7958           | 0.175       | 5571             | 14.957         | 55.829         | 55.829         |

$a_p$ - axial depth of cut, $v_c$ - cutting speed, $n$ - rotational speed, $f_z$ - feed per tooth, $v_f$ - feed velocity
Scanning of samples was realised by Zeiss Metrotom 1500 computer tomograph (Fig. 8) to obtain 3D model. The device parameters are provided in Tab. 3.

The porosity was analysed using VG Studio MAX (Fig. 9). Based on density differences inside the model it determines the amount of materials or pores.

### EXPERIMENTAL WORK AND RESULTS

Welding was realised according to the methodology, using the parameters given in Tab. 3. Since the porosity was determined based on surface roughness the welding parameters were the same for all samples. Fig. 9 shows the 5 cm cut-outs from the middle part of weld joints, ready for CT scanning.

All welded joints proved stable welding process with full penetration and even weld width along full weld length. The weld bead exhibited a small concavity because of high parameters and welding without the filler material. Weld joint surface and root were smooth without any abnormalities.

Most of the porosity was found near the fusion line of weld joints. The size (diameter) of pores in all samples varied from 0.9 up to 1.87 mm. Any correlation between the surface roughness and size of the pores was not observed since almost all samples revealed the same size range.
Analysis of variance (Fig. 11) was realised to determine the dependence of surface roughness on overall porosity volume using GraphPad Prism 8 software.

Figure 11 Graphical dependence of surface roughness on overall pores volume

Figure 12 Graphical dependence of surface roughness on overall pores surface

Table 4 shows overall volume of all pores in particular sample.

| Sample | Overall porosity volume / mm³ | Overall surface of pores / mm² |
|--------|-------------------------------|-------------------------------|
| 0 (brushed) | 4.32 | 67.15 |
| 1 | 3.53 | 95.31 |
| 2 | 6.92 | 176.54 |
| 3 | 4.93 | 72.29 |
| 4 | 3.94 | 109 |
| 5 | 4.12 | 105.38 |
| 12 | 5.49 | 147.84 |

4 CONCLUSION

The experiment was focused on finding the dependences between porosity and surface roughness in aluminium-lithium welded joints produced by laser beam welding. Porosity on prepared samples was analysed and quantified using ZEISS Metrotom computer tomograph. Analysis of Variance was used to determine the dependence between porosity and surface roughness of samples. The results showed that none of monitored factors was statistically significant so the dependences between parameters are random.

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