# FATIGUE LIFE OF LASER POWDER BED FUSION (L-PBF) ALSI10MG ALLOY: EFFECTS OF SURFACE ROUGHNESS AND POROSITY

Laboni Afroz[1]*, Mark Easton[1]**, Ma Qian[1]**, and Raj Das[1]**

*[1]Centre for Additive Manufacturing and School of Engineering, RMIT University, Melbourne, VIC 3001, Australia*
** Presenting Author email:* s3731913@stuednt.rmit.edu.au/ laboni@name.buet.ac.bd
*** Co-authors' email:* mark.easton@rmit.edu.au, ma.qian@rmit.edu.edu, raj.das@rmit.edu.au

**Abstract**

The fatigue life of components manufactured by the laser powder bed fusion (L-PBF) process is dominated by the presence of defects, such as surface roughness and internal porosity. The present study focuses on the relative effect of surface roughness and porosity in determining the fatigue properties of AlSi10Mg alloy produced by L-PBF built in the Z direction for as-built (ASB), machined (M) and machined & polished (M&P) conditions. As-built L-PBF samples possess higher surface roughness (1.5-2 µm) compared to the machined (0.8-1.0 µm) or polished ones (0.3-0.75 µm). For ASB samples, surface roughness was found to be the dominant factor affecting fatigue life. However, for M or M&P samples with relatively low surface roughness, the subsurface porosity becomes the dominant factor affecting fatigue failure rather than variations in the surface roughness. The pore size and location effects are analysed using linear elastic fracture mechanics theory, and the critical stress intensity factors (SIF) for L-PBF AlSi10Mg alloy samples are estimated.

## 1. Introduction

A major reason for the interest in developing AM parts is the possibility to reduce fuel consumption and emissions, increase payload, and drastically reduce the buy-to-fly ratio. The effect of fatigue resistance of L-PBF aluminium alloys has been given some attention in the literature; however, the findings of the various authors are not always consistent. Many suggested machining to be the most effective post-processing methodology to improve fatigue life. One of the biggest benefits of AM is the possibility of reducing the process chain, and consequently, it is preferred that the parts are utilised in their ASB state. This leads to the present study, where the fatigue life of L-PBF AlSi10Mg alloy is evaluated and compared with as-built (ASB), machined (M) and machined & polished (M&P) samples. Furthermore, the relative effect of roughness, porosity density, pore size and their location is also evaluated based on linear elastic fracture mechanics.

## 2. Results

All the samples in this study were tested for High Cycle Fatigue (HCF) according to the test standard ASTM 466. The relationship between surface roughness value and fatigue life, shown in Fig. 1, can be described as follows:

a. Surface roughness is the controlling factor for fatigue failure for ASB samples when the roughness is very high (> 2000 nm).
b. For samples having surface roughness less than 1000 nm (such as M and M&P samples), something other than surface roughness appears to be the controlling factor on fatigue.
c. For small variations in average roughness (100-300 nm) within a similar sample type, there is no notable relation between roughness and fatigue cycles.

X-ray computed tomography (CT) and Scanning Electron Microscopy (SEM) were performed on the fatigue test specimens to determine the respective population of defects, size, and their location. The effect of porosity on fatigue life can be summarized as follows:

d. The porosity density does not have a significant effect on fatigue cycles under similar loading conditions.
e. Samples surviving fewer cycles at the same stress have a larger effective pore size. For two samples with the same pore size, the one with sub-surface/internal pores has a higher fatigue cycle.

Therefore, using the porosity data from X-ray, a modified stress intensity factor ($K_{mod}$) is calculated to predict the effects of the pore size and location on fatigue cycles, as shown in Fig. 2. Kmod is calculated as

$$K_{mod} = \gamma . \sigma \sqrt{\pi \sqrt{area}} \quad (1)$$

where the geometric parameter, $\gamma$ includes both diameter and exact location of the pores. Kmod is determined based on the maximum value associated with one pore in each sample, which lies within 200 µm of the surface and is chosen in this case.

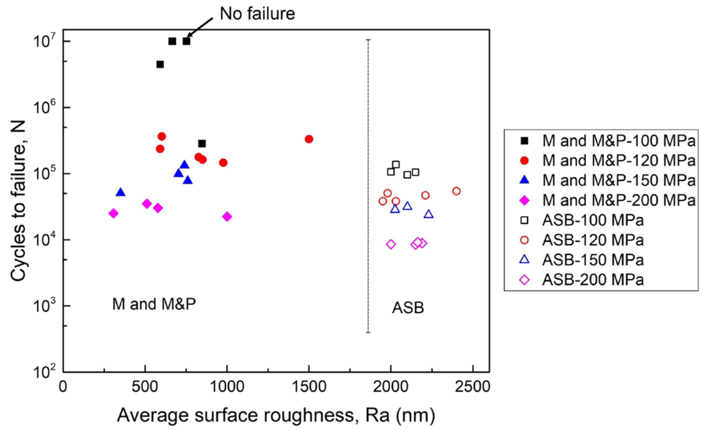


Fig.- 1: Tension-compression (R= -1) samples loaded between 100 and 200 MPa for ASB, M and M&P samples.

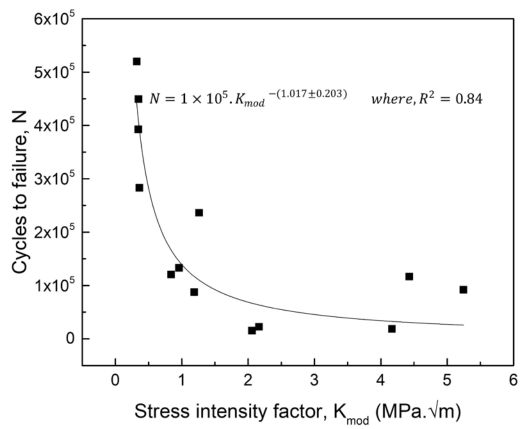


Fig.- 2: The fatigue life of M samples (R=-1) is plotted against Kmod (using the modified Y parameter in Murakami's equation)

The effect of Kmod on fatigue life is particularly prominent for lower applied stress regions (100 MPa and 120 MPa). From Fig.-2, a general equation for fatigue cycles, N can be written as follows:

$$N = 1 \times 10^5 . K_{mod}{}^{-(1.017 \pm 0.203)} \qquad where\ R^2 = 0.84 \tag{2}$$

## 3. Conclusions

This paper has shown the effect of surface roughness and the presence of porosity on the fatigue life of L-PBF-produced AlSi10Mg alloy. The ASB samples survived lower fatigue cycles than M and M&P samples at all loading conditions but particularly at lower stress levels. Under these conditions (Ra>2000 nm) it is established that the surface roughness controls the fatigue life. However, for M and M &P samples where Ra<1000 nm, fatigue life is not dependent on the surface roughness, but on the internal porosity size and location, with larger pores closer to the surface being more detrimental to fatigue life. A modified Murakami equation based on porosity data obtained from X-ray CT was fitted to the data, which could be used to predict the fatigue life of L-PBF Al10SiMg alloy fatigue life prior to testing.

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