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FINITE ELEMENT MODELLING IN PREDICTING THE EFFECT OF DEFECTS ON STRESS CONCENTRATION AND FATIGUE LIFE OF L-PBF ALSI10MG ALLOY

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Abstract

The elastic-plastic finite element analysis is performed to obtain the stress field around pores and evaluate their resultant effects on fatigue life for L-PBF (Laser Powder Bed Fusion) produced AlSi10Mg alloy. The stress field is calculated for both single and multiple pore models, where stress concentration is evaluated as a function of the pore location and its size. A multi-scale finite element (FE) model is proposed based on the inherent porosity data from Computed Tomography (CT) to predict the overall fatigue life with high (90%) accuracy. The predicted fatigue life (cycles) are calculated using the rainflow counting algorithm in fe-Safe software using the stress-strain data obtained from the proposed FE model developed using the Abaqus software. Using the proposed model, it is possible to generate S-N curves for any loading condition for a given porosity characteristic (porosity density and average pore size).

1. Introduction

Compared to traditional manufacturing, limited experimental and numerical studies have addressed the effect of pore morphology on the fatigue life of additively manufactured (AM) alloys. The formation of porosity is an almost unavoidable phenomenon in AM. Since experimental fatigue study is a time-consuming process, the numerical simulation could be an effective way to predict crack initiation sites and fatigue properties prior to a comprehensive fatigue test program. Therefore, this research aims to perform finite element (FE) analysis of AM test components by incorporating the actual porosity data (porosity fraction and pore size) obtained from micro-CT data. The present study evaluates the relative effect of pore size and location on stress concentration and the resultant fatigue life. In this context, this paper proposes a FE model to predict the fatigue life and generate an S-N curve for a full-scale test specimen. Thus, understanding the effect of porosity on stress generation and associated fatigue life data can be used as input parameters for the design of AM components and their structural integrity assessment in load-bearing structural applications.

2. Results

The stress distribution within the pores was examined to understand its effect on the overall stress increment in the components. The stress tensor results were then used to predict fatigue life under given loading conditions, considering a single-pore model. Fig. 1 shows the FE results for a single pore model, which is summarised below.

a. Shifting the pore location within the centre region of the sample (green points) does not significantly change the stress concentration around it.
b. Stress concentration starts to increase (5-15%) when the pore is within 1 mm from the surface (refers to the green points between 1.6 to 2.0 mm distance from the centre).
c. A steep increase in stress concentration (~40%) is found when the pore is within 300-350 nm of the surface (the red point).
d. The maximum stress concentration occurs (70 % increase compared to the centre pore) when the pore intersects the sample's surface (purple point).

To predict the overall fatigue life in the presence of defects, an RVE (representative volume element) model is used to consider the porosity. This RVE is generated using a python code, and the FE analysis is performed in Abaqus CAE to obtain the stress-strain data. The RVE model results are used in fe-Safe to calculate the fatigue life at different stress loading. The obtained FE fatigue life prediction data are validated with experimental results for the same alloy, as shown in Fig.2 for stress ratio R = -1.

e. At high stress loading (200 MPa and 150 MPa) conditions, the FEA predicted a fatigue life with an error of 9%.

f. The FE calculated fatigue life is nearly 43% higher than that of the experimental fatigue life at 120 MPa. On the contrary, the FE prediction is 18% lower than the experimental at 100 MPa. In the RVE model, the pore's locations are random. Besides, the FE model ignores surface roughness effect, while experimental samples showed 500-900 nm roughness. This could be another reason for the over-prediction in the FE results.

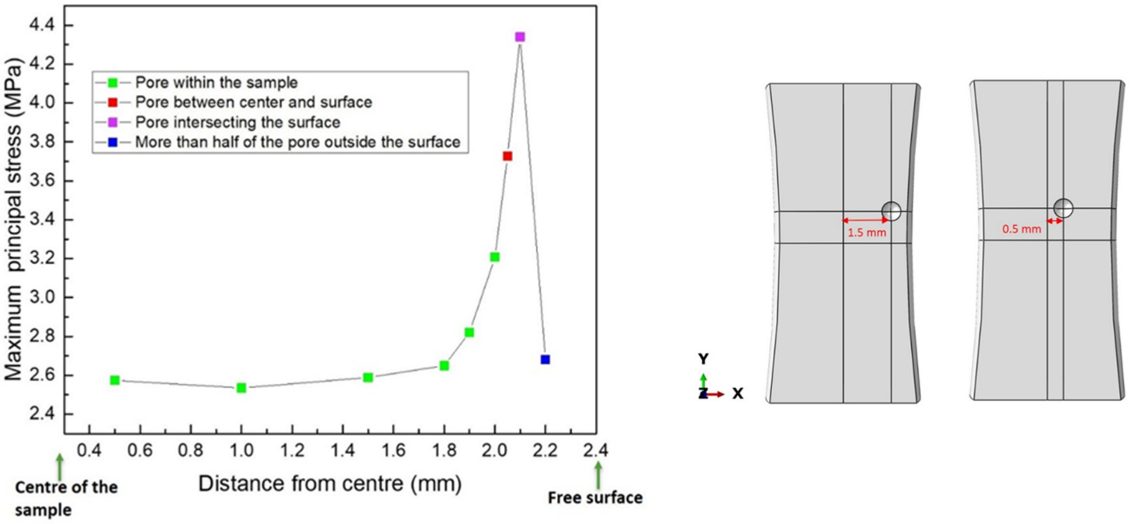

Fig.1 - Relationship between the maximum principal stress (maximum stress concentration) and the pore location from the centre of the part (as shown on the right).

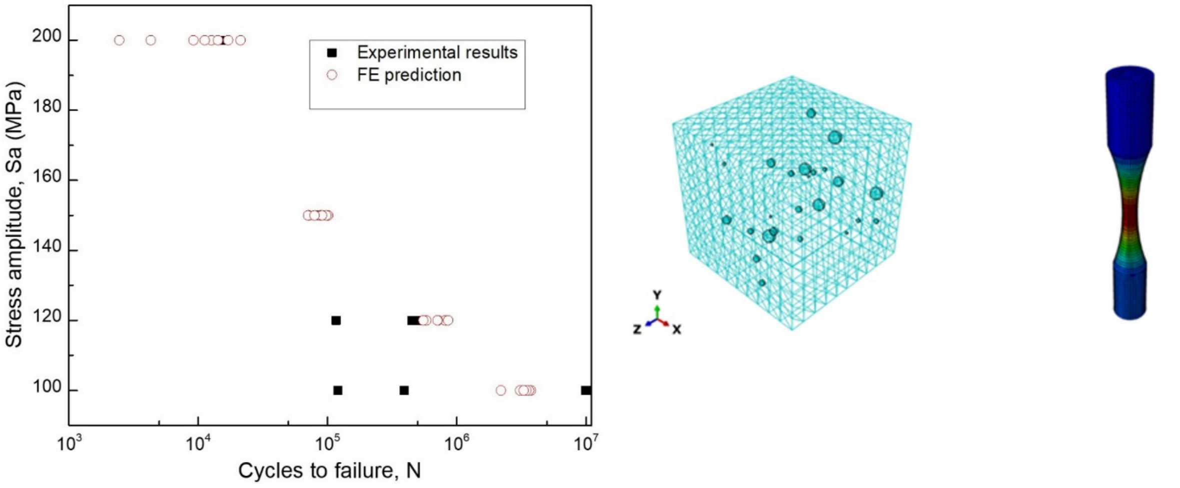

Fig.2 - Comparison of the FE model predictions and the experimentally determined fatigue life for R =-1 (the RVE model is shown on the right).

3. Conclusions

In this study, the effects of, pore size and location on the stress concentration and fatigue life of L-PBF AlSi10Mg alloy are assessed using FE analysis. A comparative study shows that the pore location has more contribution in producing the stress concentration than the pore size. A significant stress concentration occurs near the surface pores compared to pores at the centre. The proposed FE model reasonably predicts the fatigue life and generates an S-N curve, when known porosity data (pore density, size, and location) is used as an input.