FATIGUE LIFETIME ESTIMATION OF ELECTRON BEAM MELTED MICRO-SIZED PARTS BASED ON SURFACES REGENERATED BY MACHINE LEARNING APPROACH

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Abstract

The fatigue response of additive manufactured parts, using the electron beam melting technique, is detrimentally affected by their surface defects. These surface defects, produced by the multiple phenomena during the additive manufacturing (AM) process, are the main origins of premature crack initiation and lead to subsequent fatigue failure. This study focuses on estimating the fatigue lifetime of electron beam melting (EBM) manufactured Ti-6Al-4V micro-sized parts using a combination of machine learning and finite element modelling. A Generative Adversarial Network (GAN) is trained to generate 2D surface profiles of the EBM-manufactured Ti-6Al-4V micro-sized parts based on experimental data taken from the literature. Next, the regenerated 2D surface profiles are randomly used to construct 2D Finite Element (FE) models to find and calculate the stresses at critical defects. Finally, Continuous Damage Mechanics (CDM) and Theory of Critical Distance (TCD) are implemented to estimate the fatigue lifetime. This way, hundreds of simulations are performed using regenerated surface profiles. The obtained results show that using both GAN and finite element simulation makes it possible to numerically reproduce the observed fatigue scatter data which is an inherent characteristic of additively manufactured materials.

1. Introduction

Through the combination of voids and micro-sized struts, additively manufactured lattice structures have significant advantages in weight reduction, thermal insulation, high specific strength, and energy damping, showing great potential in the aerospace, biomedical, and transportation industries. The recent advancement of powder-bed based AM technologies such as EBM facilitates the manufacturing these complex structures. However, the surface defects in the micro-sized struts of lattice structures produced by the layer-based AM process become the main origins of stress concentration and lead to fatigue failure under cyclic loads and enhance the inherent fatigue scatter characteristics. A thorough understanding of the fatigue behaviour for EBM-manufactured micro-sized parts requires extensive full-scale fatigue testing, which is costly and time-consuming.

Therefore, this work proposed a numerical method based on GAN and finite element modelling to investigate the fatigue behaviour of EBM-manufactured Ti-6Al-4V micro-sized parts. GAN is a machine learning framework involving two neural networks, a generator and a discriminator. The fake surface profiles produced by the generator are judged by a discriminator, and the generator will be punished if the generated surface profiles are not qualified and trained to generate new surface profiles until the discriminator cannot identify the difference between the generated surface profiles and the input dataset. With this, the surface profiles of EBM-manufactured micro-sized parts are virtually manufactured, and the irregularity of the surface defects can be reproduced.

FE analysis is used to calculate the stresses at defects and find the critical defect. The axisymmetric radial slice of X-ray tomography is binarized and imported into Abaqus software to build the FE model. The surface profile is finely meshed, and the meshing size at the defects is 1μm. The FE modelling process is shown in Fig.1 (a). Three hundred numerical simulations are performed using Python scripts inside Abaqus to model the regenerated surface profiles, which are randomly selected. The axial fatigue stress is also applied randomly between 150MPa to 360MPa to cover the experimentally tested loading range. Finally, the fatigue lifetime of EBM-manufactured micro-sized parts is estimated using a fatigue lifetime prediction model which is based on combination of CDM and TCD.

2. Results

Two vertically manufactured surface profiles from X-ray tomography are used as input dataset to train the GAN in order to regenerate 61 qualified surface profiles for the subsequent FE analysis. The surface roughness of the regenerated surface profiles (R_a 44.29 ± 3.23) shows similar values with the two input surface profiles (R_a 42.26 ± 3.23), and the R_a values of the radial slices extracted from literature 44.10 ± 4.36. The FE simulation results indicate that:

- The fatigue lifetime of the EBM manufactured micro-sized part shows a weak correlation with the surface roughness parameters (Pearson's R < 0.02). Instead, the critical defect plays a dominant role, while the critical defect is not always located at the deepest defect which depends on the defect geometry.
- Because of the complexity of defect geometry, the peak stress at the defect tip cannot be accurately calculated using the stress concentration factor Kt. The linear correlation factor between the simulated peak stress and the calculated peak stress using Kt is 0.68.

The estimated fatigue lifetime of EBM-manufactured Ti-6Al-4V micro-sized parts using regenerated surface profiles is shown in Fig.1 (b). The estimated fatigue lifetime shows good conformity with the experimental data. With the enrichment of defects irregularity, the fatigue scatter characteristics of EBM-manufactured Ti-6Al-4V micro-sized parts are successfully reproduced. The probabilistic stress-life (P-S-N) curves based on Weibull distribution are shown in Fig. 2. 5%, 50%, and 95% failure curves are given, which facilitates the fatigue-limited based structure design.

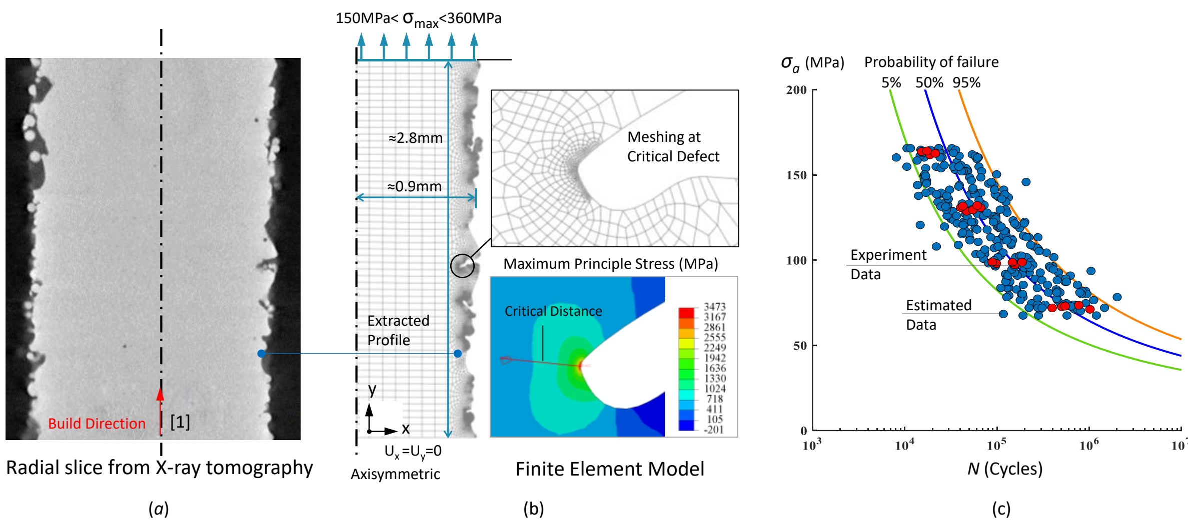

Fig. 1. (a) radial slice from a X-ray tomography; (b) 2D FE model; (b) Probabilistic stress-life curve of estimated fatigue lifetime. [1] Persenot et al. International Journal of Fatigue118 (2019): 65-76.

3. Conclusions

This work presents a numerical approach to use surface profiles regenerated by a GAN architecture to predict the fatigue lifetime of EBM-manufactured Ti-6Al-4V micro-sized parts. The surface roughness values of regenerated surface profiles present similar values to the input surface profiles. The FE analysis results indicate that the surface roughness values have less influence on the fatigue lifetime, while the critical defect plays a dominant role. The fatigue scatter characteristics of EBM-manufactured Ti-6Al-4V micro-sized parts can be reproduced using regenerated surface profiles and randomly based numerical simulations. The obtained estimated fatigue lifetime is satisfactory compared with the experimental data.

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