ORIENTATION-DEPENDENT FATIGUE ASSESSMENT OF TI6AL4V MANUFACTURED BY L-PBF

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Abstract

The fatigue behaviour of as-built parts produced by means of Laser-Powder Bed Fusion process (L-PBF) is primarily influenced by the presence of stress raisers on the surface, whose morphology strongly depends on the relative orientation between the surface and the build direction. This study aims to shed light into the factors representing the surface morphology that correlate with the fatigue performance of L-PBF Ti6Al4V specimens manufactured in different orientations. A fracture mechanics model based on measurable roughness parameters was employed for the prediction of the fatigue properties in both the finite life and endurance limit regions.

1. Introduction

The large diffusion of Ti6Al4V alloy for Additive Manufacturing applications is well justified by its outstanding material properties, i.e. excellent ratio between static mechanical properties and density, good corrosion resistance, excellent weldability and bio-compatibility. These properties make the Ti6Al4V alloy very captivating for the aerospace and medical industries, especially in relation to the additive manufacturing processes. The fatigue performance of Ti6Al4V L-PBF parts has been observed to be generally reduced and subjected to a larger variability due to the presence of stress raisers introduced by the manufacturing process, i.e. internal defects and surface anomalies. A wider adoption of the Ti6Al4V alloy in the AM industry requires a further improvement on the capability to predict the fatigue performance of AMed parts and the key factors affecting it. This study aims to shed light into the effect of the surface orientation on the fatigue behavior of the Ti6Al4V alloy correlating measurable surface roughness parameters with the fatigue life in a fracture mechanics-based framework.

2. Results

Fatigue crack growth specimens were printed in vertical and horizontal orientation to measure the crack growth rates as a function of the applied ΔK in the threshold and Paris regimes, for load ratio $-1 < R < 0.7$ (Fig. 1, experimental set-up). Additional net-shaped fully-dense fatigue specimens were printed in four different build orientations, with negligible impact of residual stresses and internal porosity. These specimens were tested under 4-point bending configuration to establish the entire fatigue performances in the infinite and finite life regimes. FV optical microscopy and XCT scanning were implemented to study the surface morphology subjected to fatigue stress during the tests (Fig. 1, analysis of rough surface profiles). Important roughness parameters were obtained and correlated with the initial defects leading to failure. A crack propagation model based on the NASGRO equation was developed to perform life predicitons. Fig 1 (material properties) shows the crack growth data as a funciton of the load ratio R and the specimen orientation. The specimen orientation sligthly influences fractures propagating at negative load ratio R, while no differences were observed between vertical and horizontal specimens at positve load ratios. The life prediciton algorithm firstly considers an average defect size for each orientation measured from the fracture surfaces. The calculations were observed to be consistent with the experimental data, Fig. 1 (life predictions). In addition, the calculations were also performed considering a shielding factor induced by the rough surface which was seen to have a paramount importance in the endurance limit region.
Upon validation, the life prediction model was successfully used adopting the roughness parameter $R_{v,max}$ as the initial equivalent flaw size and the shielding factor calculated from other roughness parameters.

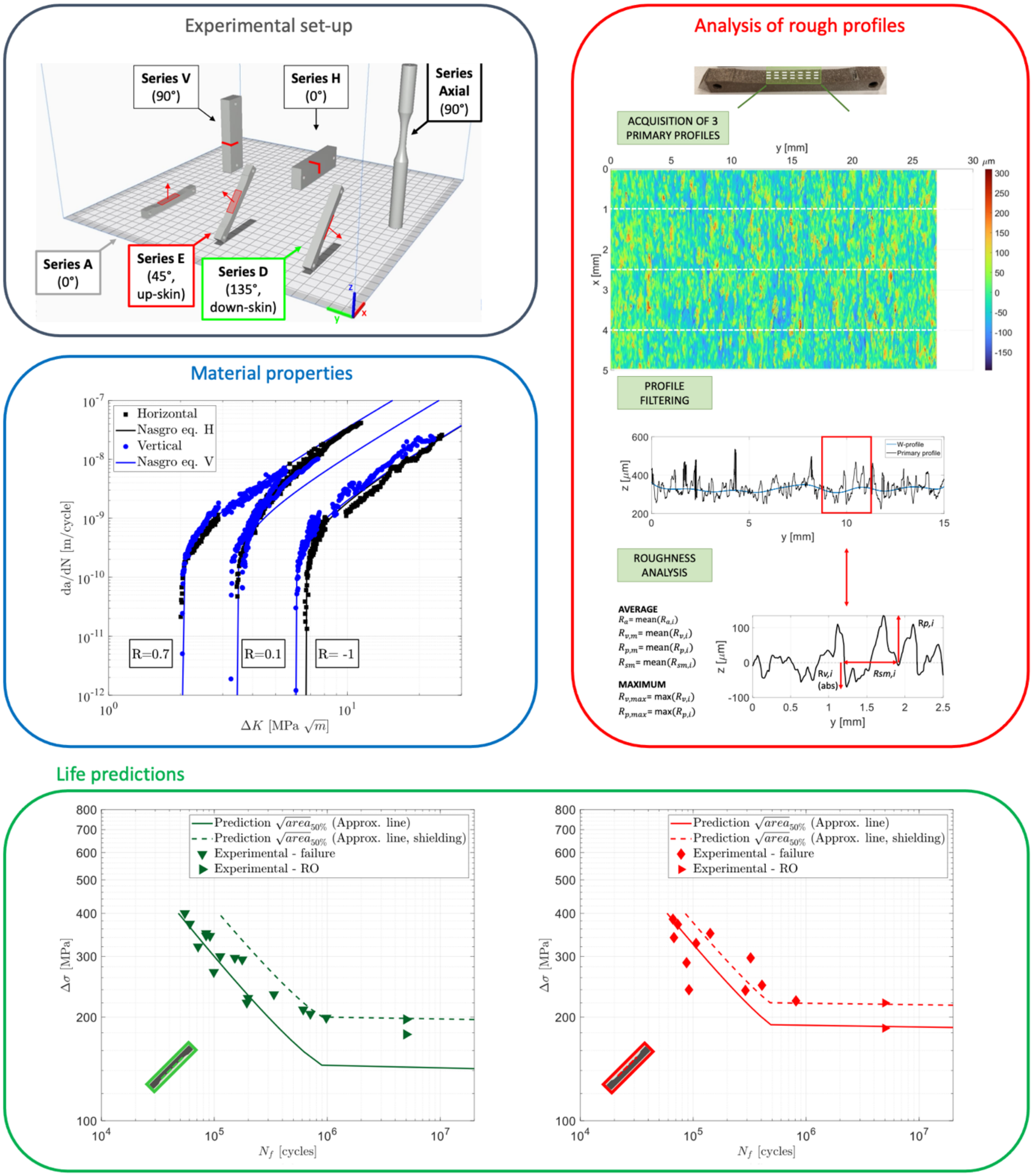

Fig.1 Experimental results and life predictions of net-shape Ti6Al4V specimens manufactured by L-PBF process in different orientations.

3. Conclusions

This study explored the impact of the as-built surface condition on the fatigue performance of a L-PBF Ti6Al4V alloy. The tests showed that the surface orientation has a paramount effect on the fatigue strength. Roughness analyses from surface profiles were acquired with FV optical microscopy and XCT. The maximum valley depth $R_{v,max}$ was found to be a suitable roughness parameter that can be adopted as the initial equivalent defect size in a fracture mechanics-based life prediction algorithm.