Multiaxial fatigue behavior of SLM Ti6Al4V alloy: X-ray computed μ-tomography analysis

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Abstract

Crack formation and propagation phenomena in selective laser melting (SLM) Ti-6Al-4V alloy samples were analyzed under combined axial and torsional fatigue loads. In fact, SLM defects lead to a lower fatigue strength and a larger fatigue life variation with respect to to conventionally manufactured parts. Internal defects were captured by X-ray computed μ-tomography (μ-CT) and their evolution was monitored by interrupted fatigue tests. Critical defects were analyzed by the strain intensity factor (SIF) using two different models based on the Murakami's method: a modified Smith-Watson and Topper (MSWT) criterion and a virtual strain energy (VSE) criterion. The trend of the crack growth rate was analyzed by the effective defect area at different number of fatigue cycles. The μ-CT data were also used to build finite element models (FEM) of cracked samples to analyze the whole stress-strain distribution in the near crack tip region.

1. Introduction

Selective laser melting (SLM) technology is receiving great attention in last years as it allows rapid prototyping and manufacturing of high-quality end-use metal products, and a special effort was devoted to the Ti-6Al-4V alloy system [1]. In fact, these alloys are successfully used in several high demanding applications thanks to their advantageous strength-to-weight ratio, good corrosion resistance, and elevated service temperature [1]. However, SLM components typically have a lower fatigue strength and a larger scatter in fatigue life compared to traditionally manufactured parts [2]. This is due to different properties, such as surface roughness, porosity, defects, residual stress, and microstructural characteristics. Usually, pores, lack of fusion (LOF), and inclusions are common features of SLM parts. LOF defects are due to unmelted powder between the deposited layers. These have a larger and irregular shape and are generally oriented along the build direction. Pores usually have a regular shape (i.e., near-spherical shapes) and contain trapped gases [3]. It was demonstrated that LOF defects and pores are the primary cause of fatigue crack initiation in SLM parts. To this end, X-ray microtomography (μ-CT) can be used as an efficient non-destructive method to capture microstructural features and defect in SLM parts, due to its high-resolution and accuracy.

Within this context, the fatigue crack growth behavior of SLM Ti-6Al-4V alloy samples, subjected to combined axial and torsional loading, was analyzed in this investigation. Defect distribution was captured by X-ray microtomography at the μTomo experimental station of the STAR Lab research infrastructure (University of Calabria). Critical defects, were identified and monitored by interrupted fatigue tests. Furthermore, μ-CT measurement data were also used to generate finite element models (FEM) of defects within a representative volume. Effective strain intensity factor (SIF) of critical defects were analyzed by two models based on the Murakami's method: a modified Smith-Watson and Topper (MSWT) critical plane criterion [4-5] and the Liu's virtual strain energy (VSE) criterion [6]. The crack growth rate curve was obtained by measuring the effective area at different fatigue cycles. Finally, FEA provided useful insight into the effects of SLM defect on crack formation and propagation mechanisms.

2. Methods and summary results

Tubular SLM Ti-6Al-4V alloy samples were subjected to combined in-phase axial and torsional fatigue loads. μ-CT scan were carried out by interrupted fatigue tests to investigate the crack growth behavior (see Fig. 1.a). A sub-volume of material containing larger defects was detected and analyzed by finite element simulations (Fig. 1.b). Within this sub-volume, the critical defects were identified and analyzed by the effective strain intensity factor (SIF) using two models based on the Murakami's method: a modified Smith-Watson and Topper (MSWT) critical plane and the Liu's virtual strain energy (VSE) criteria. The evolution of effective defect area was obtained from μ-CT scan as a function of the fatigue cycles as shown in Fig. 1.c.

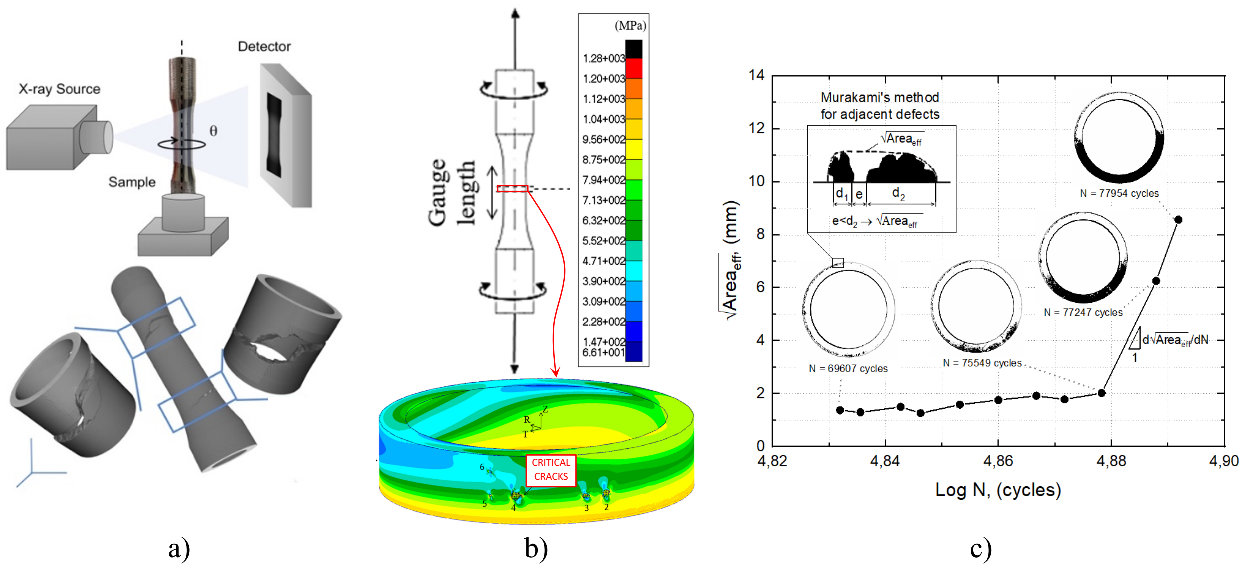

Fig. 1 – a) Schematic of μ-CT measurement with 3D reconstruction of internal defects; b) Finite element model of a sub volume with critical defects; c) Fatigue crack growth behavior and Murakami's method for adjacent defects.

3. Conclusions

Multiaxial fatigue response of selective laser melting Ti-6Al-4V alloy samples was analyzed in this investigations. Crack formation and evolution were captured by X-ray computed μ-tomography and analyzed by finite element simulations and modified Murakami's methods. Results highlighted the great effects of SLM defects on the crack formation and propagation mechanism.

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