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ScienceDirect

Procedia Engineering 213 (2018) 5–16

Procedia Engineering

www.elsevier.com/locate/procedia

7th International Conference on Fatigue Design, Fatigue Design 2017, 29-30 November 2017, Senlis, France

Fatigue Design with Additive Manufactured Metals: Issues to Consider and Perspective for Future Research

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Abstract

Additive manufacturing (AM) is a state of the art technology enabling fabrication of complex geometries, in addition to providing other advantages as compared to the traditional subtractive manufacturing methods. However, a wide variety of factors significantly influence fatigue behavior and structural performance of components made of AM metals. In addition to the fabrication process parameters, these include the effects of build direction, surface roughness, residual stresses, and heat treatment, and multiaxial stress states. At the microstructural level, defects such as pores and lack of fusion particles, as well as other microstructural features affect the behavior. In this paper, first a brief review of the aforementioned factors affecting the fatigue behavior will be presented. Then some experimental multiaxial fatigue data for selective laser melting (SLM), which is a powder bed fusion (PBF) metal AM process, of a common Ti alloy (Ti-6Al-4V) with applications in many industries are presented and discussed. The effects of surface finish, heat treatment, and stress state will be evaluated, as well as failure mechanisms in different life regimes and the role of defects. Finally, some additional factors that must be considered before wide acceptance of the AM technology in critical load bearing applications will be addressed.

Peer-review under responsibility of the scientific committee of the 7th International Conference on Fatigue Design.

Keywords: Additive manufacturing, Multiaxial fatigue, Microstructure, Heat treatment, Residual stresses, Build orientation, Surface roughness

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1877-7058
Peer-review under responsibility of the scientific committee of the 7th International Conference on Fatigue Design.
10.1016/j.proeng.2018.02.002

1. Introduction

Nomenclature

$2N_f$	Reversals to failure
N_f	Cycles to failure
γ_a	Shear strain amplitude at surface
γ_{mid}	Shear strain amplitude at mid-section
$\bar{\sigma}_a$	von Mises equivalent stress amplitude
$\bar{\sigma}_{1a}$	Maximum principal stress amplitude
ε_a	Strain amplitude
$\bar{\varepsilon}_a$	von Mises effective strain amplitude
τ_a	Shear stress amplitude at surface
τ_{mid}	Shear stress amplitude at mid-section

Additive Manufacturing (AM) is a state of the art process which enables fabrication of complex geometries and provides several advantages over the traditional subtractive manufacturing methods. Among the advantages of AM process is the possibility of fabricating complicated geometries which are difficult or impossible to build using traditional manufacturing. In contrast to subtractive manufacturing, in which a part is made by removing the material from a block, in AM the part is built with a close to final shape geometry with little or no need for material removal, therefore, there is much less material waste. On site fabrication is amongst the other advantages of AM technique.

AM metallic parts are commonly fabricated via Powder Bed Fusion (PBF) and Directed Energy Deposition (DED) processes. In PBF, a metal powder is melted selectively via laser or electron beam over the previous layer, while in DED, both energy source which could be laser or electron beam, and the material which is powder or wire infuse simultaneously. For more information about the fabrication process of AM parts the reader is referred to review articles in the literature, for example to [1, 2]. Several process parameters such as laser power, scanning speed and strategy, and layer thickness are amongst the important parameters which could directly influence the material microstructure and, therefore, behavior.

Similar to most other components in different industries, AM parts typically undergo cyclic loadings through their service life. Therefore, understanding their fatigue behaviour is essential to be able to widely adopt the technique in different industries while preventing fatigue failures. Moreover, multiaxial stresses are common for many components and structures. Even under uniaxial loading conditions, the stress state might be multiaxial, which could be due to the geometry complexity, notches, and residual stresses [3, 4].

This paper is not intended to be a review paper, but rather, an overview sort of paper, in which several important issues related to AM techniques are discussed. Although additive manufacturing is becoming more popular in many industries, it has been shown that a wide variety of factors could significantly influence their fatigue behaviour and structural performance of the components made by this technique. In this paper, first a brief review of several important factors including fabrication process parameters, build orientation, surface roughness, residual stresses, and heat treatment is presented. Then, some experimental multiaxial fatigue data for a common Ti alloy (Ti-6Al-4V) made via Selective Laser Melting (SLM), which is a PBF process will be presented. Finally, a summary and some perspective for future research is provided.

2. Important factors to consider in fatigue design with AM

Similar to many other mechanical components, most of the components made of this technique undergo cyclic loading throughout their service life, therefore, fatigue failure is a major concern. While AM offers several