Available online at www.sciencedirect.com

ScienceDirect

Procedia Structural Integrity 5 (2017) 239–246

Structural Integrity Procedia

www.elsevier.com/locate/procedia

2nd International Conference on Structural Integrity, ICSI 2017, 4-7 September 2017, Funchal, Madeira, Portugal

Analysis of fatigue crack propagation in laser sintering metal

L.F.P. Borrego[a,b]*, F.V. Antunes[a], J.A.M. Ferreira[a], J.D. Costa[a], C. Capela[a,c]

[a] *CEMMPRE, University of Coimbra, Department of Mechanical Engineering, Rua Luís Reis Santos, 3030-788, Coimbra, Portugal*
[b] *Instituto Politécnico de Coimbra, ISEC, Department of Mechanical Engineering,Rua Pedro Nunes, 3030-199 Coimbra, Portugal*
[c] *Instituto Politécnico de Leiria, Department of Mechanical Engineering, ESTGMorro do Lena – Alto Vieiro, 2400-901 Leiria, Portugal.*

Abstract

Laser sintering metal has recently been used in the manufacture of components for different applications like aerospace or medicine. The approach to engineering design based on the cracks propagation assumption applying the concepts of linear elastic fracture mechanics (LEFM) is commonly used for aerospace engineering. However, fatigue crack propagation is linked to irreversible and non-linear mechanisms at the crack tip, therefore LEFM parameters can be successfully replaced by non-linear crack parameters, namely the plastic CTOD. A model linking da/dN with plastic CTOD is proposed here to characterize fatigue crack propagation. A comparison is made with other materials showing that for the same plastic CTOD the laser sintering material has a relatively large crack growth rate.

Keywords: Laser sintering material; fatigue crack propagation; plastic CTOD

1. Introduction

Laser sintering metal (LSM) has recently been used in the manufacture of components for different applications like aerospace or medicine. Many studies, mainly focused on the influence of sintering parameters and selection of metal powder on microstructure of the sintered parts, state that for some materials, LSM parts are able to offer static mechanical properties comparable to the properties of conventionally bulk materials. However, on service the

* Corresponding author. Tel.: +351 962560101; fax: +351 239790331.
E-mail address: borrego@isec.pt

2452-3216 © 2017 The Authors. Published by Elsevier B.V.
Peer-review under responsibility of the Scientific Committee of ICSI 2017
10.1016/j.prostr.2017.07.123

components are typically dynamically loaded, for which additional work is needed to fully understand the fatigue behavior and the relevant control parameters.

The analysis of fatigue crack propagation is usually conducted by relating the crack advance per unit cycle, da/dN, to the stress intensity factor range, ΔK. At intermediate values of ΔK, a power law relationship is generally observed. For long cracks, in the small-scale yielding range, the da/dN-ΔK relationship retains the advantage of Linear Elastic Fracture Mechanics (LEFM), namely the invariance relative to the shape and size of cracked solids. This linear-elastic parameter, surprisingly, was able to describe the rate of plastic processes at the crack tip. Later, Rice (1967) demonstrated that the small-scale cyclic plasticity at the crack tip was, indeed, controlled by ΔK. Nevertheless, da/dN-ΔK relations have several limitations, namely: (i) such curves are completely phenomenological, not derived from physics, and the fitting parameters have units with no physical justification; (ii) such curves are only valid in the small-scale yielding range; (iii) and da/dN depends on other parameters, including the stress ratio and the load history.

In order to overcome the difficulties related to the application of K to the analysis of fatigue crack growth (FCG), several concepts have been proposed. Crack closure (Elber, 1970) has been used to explain the effects of mean stress, overloads, short cracks and specimen thickness, while the T-stress has been used to explain the effect of specimen geometry (Lugo, 2011). Donald and Paris (1999) and Kujawski (2001) have introduced the concept of partial crack closure, so called, which recognizes that a significant contribution to fatigue damage occurs in the load range below the opening load as measured by the compliance technique. Closure, or interference of crack faces, only partially shields the crack tip from damaging action due to cyclic loading. Christopher *et al.* (2007) proposed a novel mathematical model based on the stresses around the crack tip, which has four parameters were used to characterize the stress field. However, these concepts only mitigated the problem and raised new issues.

In fact, fatigue crack growth is caused by crack tip plastic deformation, therefore ΔK parameter must be replaced by a non-linear crack tip parameter. The non-linear parameters identified in the literature review made by Antunes *et al.* (2015) were the range of cyclic plastic strain, the size of reversed plastic zone, the total plastic dissipation per cycle and the crack opening displacement. The crack opening displacement (COD) is a classical parameter in elastic-plastic fracture mechanics, still widely used nowadays. It has a physical meaning and can be measured directly in experiments. In the finite element analysis, the displacement of the first node behind the crack tip is generally used as an operational crack tip opening displacement (CTOD). The capabilities of CTOD to study crack closure and fatigue crack growth were fully demonstrated in previous work of the authors (Antunes, 2017).

The main purpose of the present work is to define a da/dN versus plastic CTOD relation for the laser sintering AISI 18Ni300 maraging steel. Fatigue crack propagation, da/dN, was obtained and afterwards a numerical study was defined, replicating the experimental procedure in order to obtain the plastic CTOD. The numerical model intended to be realistic in terms of geometry of the specimen and crack, in terms of loading and in terms of material behavior. The accurate modeling of material hardening is of major importance for the quality of numerical predictions. The behavior of the material was obtained from low-cycle fatigue experimental tests with smooth specimens tested under constant amplitude strain range. The stress-strain loops were used for the analytical fitting of hardening models. Finally, the da/dN versus plastic CTOD model was used to predict fatigue crack propagation for load blocks. The development of da/dN versus plastic CTOD relations is based on two basic assumptions: (i) that fatigue crack growth is intimately linked to crack tip plastic deformation. (ii) that the CTOD is able to quantify the plastic deformation occurring at the crack tip.

2. Experimental fatigue crack growth

Fatigue crack growth tests were carried out at room temperature using a 10 kN capacity Instron Electropuls E10000 machine, with a frequency within the range 15–20 Hz. conducted following the recommendations outlined in ASTM E647 standard using C(T) specimens (see Figure 1a). Specimens were produced by laser sintering with a thickness of 3 mm. The final surface finishing was achieved by high-speed mechanical polishing.

The crack length was measured from a travelling microscope, with magnification of 45x, and with an accuracy of 10 μm. The five-point incremental polynomial method was used to obtain the fatigue crack growth rates (FCGR). The applied loads were P_{max}=1488.4 N and P_{min}=74.4 N, therefore with a stress ratio R=0.05. Figure 1b shows da/dN versus ΔK results in log-log scales.