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ScienceDirect

Procedia Structural Integrity 7 (2017) 67–74

Structural Integrity Procedia

www.elsevier.com/locate/procedia

3rd International Symposium on Fatigue Design and Material Defects, FDMD 2017, 19-22 September 2017, Lecco, Italy

A novel test method for the fatigue characterization of metal powder bed fused alloys

Gianni Nicoletto*

University of Parma, Dept. of Engineering and Architecture, 43124 Parma, Italy

Abstract

This research addresses the conflicting factors of high costs of fatigue testing and large number of influencing factors that need to be investigated for PBF material and process qualification. Metal powders are remarkably expensive, the PBF production process requires expensive systems and fatigue testing requires multiple specimens (depending the required degree of confidence) to characterize a single material/process combination. In this paper a novel fatigue test method aimed at the peculiar needs of PBF technology is initially presented and fatigue data obtained on Direct Metal Laser Sintering Ti6Al4V are validated against standard rotating bending test results. Then, the link between microstructure and directional fatigue behavior is demonstrated using the present methodology and SLM Inconel 718: namely, the stress direction parallel to build direction is the most severe. Finally, the new test method is applied to the investigation of the fatigue notch sensitivity of DMLS Ti6Al4V in relation to the notch fabrication process. Round notches in specimens with opposite fabrication orientations (i.e. up-skin vs down-skin) resulted in two notch fatigue factors and the up-skin notch has a better fatigue strength than the down-skin notch.

Peer-review under responsibility of the Scientific Committee of the 3rd International Symposium on Fatigue Design and Material Defects.

Keywords: Fatigue, test method, powder bed fusion, Ti-6Al-4V , IN718, notch

* Corresponding author. Tel. +39 0521 905884. Fax. +39 0521 905705.
E-mail address: gianni.nicoletto@unipr.it

2452-3216
Peer-review under responsibility of the Scientific Committee of the 3rd International Symposium on Fatigue Design and Material Defects.
10.1016/j.prostr.2017.11.062

1. Introduction

Additive manufacturing (AM) embraces a number of different processes and materials. The common link is the possibility of producing functional parts of complex geometry directly from a CAD file with minimum material and energy waste. Powder bed fusion (PBF) is one of the seven AM technologies identified by ISO/ASTM 52921 norm and it is mainly aimed at producing parts using metal alloys such as Titanium, Ni-based super alloys, Cr-Co alloys and Al/Si alloys. Alternative acronyms falling under the same denomination are: SLM (selective laser melting), DMLS (direct metal laser sintering) where a laser is the energy source and EBM (electron beam melting) where the source is an electron beam. In PBF, the concentrated thermal energy source selectively fuses thin regions of a powder bed that quickly solidify. After recoating, another layer is selectively melted. The process is repeated until the entire part is built layer-by-layer, see Bandyopadhyay and Bose (2016). To industrialize the process as well as design and qualify the PBF part, material quality has to be controlled and the mechanical properties determined and guaranteed. The PBF technology is penetrating in high-value-added industrial sectors such as aerospace, medical, energy, motorsport etc., where the fatigue performance is a critical selection and design parameter, see Li et al (2016).

One of the major challenges of the PBF technology is the poor fatigue behavior of the rough as-built surfaces. The fatigue behavior of AM parts is dominated by the rough surface rather than by internal defects. The roughness of the as-built AM surface is the result of several mechanisms, for example, balling, stair-stepping, and partially melted powder grains attached to the as-built surface, Gong et al (2013). When a part has a complex geometry it may be too costly to machine all surfaces considering that some of them may not be accessible. So the link between surface quality and fatigue needs to be further understood.

This research addresses the conflicting factors of high costs of fatigue testing and large number of influencing factors that need to be investigated for PBF material and process qualification. Metal powders are remarkably expensive, the PBF production process requires expensive systems and fatigue testing requires multiple specimens (depending the required degree of confidence) to characterize a single material/process combination.

In this paper the novel fatigue test method of Nicoletto (2016) is initially presented along with consideration cost and time savings that motivates its development and application when applied to the qualification of AM process. The quality of the obtained data is verified using standard rotating bending test specimens oriented in the build direction as reference. The experimental evidence of a directional fatigue behavior is in investigated in SLM Inconel 718. The interaction of the fatigue behavior and notch geometry in as-built Direct Metal Laser Sintering (DMLS) Ti6Al4V is originally studied and discussed.

2. Novel fatigue test method for PDF metals

2.1. Motivation and specimen geometry

Fatigue testing of PBF metals to reach process qualification and design data is a remarkable task considering the large number of influencing factors that need to be investigated being the systems now reaching maturity and stability of process quality. Cost and time are the conflicting factors because metal powders are remarkably expensive, the PBF production process requires expensive systems and fatigue testing requires multiple specimens (depending the required degree of confidence) to characterize a single material/process combination.

Planning a fatigue testing campaign involves selection of a standard, specimen geometry, test equipment, test parameters, etc.. Adoption of the fatigue test standards such ASTM involves the adoption of a push-pull specimen geometry, which is then machined to fit to the test machine. Suitable bulky ends are needed to machine the gripping heads without the risk of failure outside the control section. Fatigue testing involves use of a costly servo hydraulic machine or a resonating test machine.

Alternatively, the rotating bending configuration has been recently adopted for fatigue testing of AM metals, Mower and Long (2016). For a comparable minimum cross-section, the specimen can be relatively smaller than the push-pull specimen as shown in Fig. 1. If the as-built condition is to be investigated only the Z-direction can be explored (i.e. axis of the specimen parallel to build direction) with the rotating and push-pull geometry as the two specimen configurations are self-supporting and the surface can be left unmodified. That means that loading is made