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ScienceDirect

Procedia Structural Integrity 7 (2017) 149–157

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

Influence of build orientation on static and axial fatigue properties of maraging steel specimens produced by additive manufacturing

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Abstract

Additive manufacturing involves a layer-by-layer build-up of mechanical parts and it is a manufacturing technology that can be adopted with different engineering metal materials like steels, aluminium and titanium alloys. Aim of the present investigation is to analyse the influence of the build orientation on static and axial fatigue properties of maraging steel specimens manufactured by Direct Metal Laser Sintering (DMLS) of EOS metal powders. After manufacturing, some of the specimens were subjected to age hardening heat treatment (490 °C for 6 hours, followed by air cooling). Both heat treated and as-manufactured specimens have been built at 0° as well as at 90° orientation with respect to the specimen's axis. Analyses of the crack initiation point are performed in order to investigate the fatigue failure mechanisms. Finally, the fatigue strength of the additively manufactured specimens was compared with that exhibited by vacuum melted specimens of the same steel reported in literature.

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

Keywords: Additive manufacturing; Maraging steel; Axial fatigue

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Peer-review under responsibility of the Scientific Committee of the 3rd International Symposium on Fatigue Design and Material Defects.
10.1016/j.prostr.2017.11.072

1. Introduction

Additive manufacturing (AM) techniques have been known for more than 20 years and were at first applied to rapid manufacture prototypes, where porosity was not an issue (Beaman and Deckard, (1990)). In the last 10 years AM of parts increased thanks to the advancement of technology, which led to improved part density and quality with the enormous advantage of design freedom (Kruth et al. (2005); Rannar et al., (2007); Murr et al., (2012); Kranz et al., (2015)).

Nomenclature

DMLS	direct metal laser sintering
Δf	specimen deflection
NT	not aging hardening heat-treated specimens
T	aging hardening heat-treated specimens
R_a	surface roughness
ε_m	mean strain
ε_R	elongation at fracture
σ_a	cyclic stress amplitude
σ_R	ultimate tensile strength

AM of metals can be presently performed by using different methods: Laser Beam Melting (LBM), Electron Beam Melting (EBM) and Laser Metal Deposition (LMD) (also known as Direct Energy Deposition (DED)) (Yan and Yu, (2015)). Irrespective of the adopted technology, the starting point of metal AM processes is a 3D CAD model, which is sliced in the computer virtual environment into thin layers (the layer thickness being in the range 20 micrometers – 1 mm). Afterwards, the physical component is built by layer-by-layer deposition and locally melting of the material using a heat source (the laser beam or the electron beam) depending on the AM process.

All AM processes involve complex thermal cycles, where cooling rates are reported to be extremely high, i.e. on the order of 10^3–10^8 K/s in LBM processes (Gu et al., (2012)). Since heat conduction is likely to be more effective in the building direction than in the transversal direction, elongated grain shapes have been observed leading to anisotropy of microstructure and of resulting mechanical properties.

The adopted process of AM of metals and the post-manufacturing heat and surface treatment result in final static and fatigue properties of the part. With the advancement in the AM technology dense part can now be achieved as compared to conventional manufacturing processes (cast or wrought parts). It is reported that high density is the first goal in AM process optimization in order to reduce pore formation (Everton et al., (2016)), which is detrimental in static and, to a larger extent, in fatigue strength. Generally speaking, microstructure of AM parts is finer than that obtained by means of traditional processes (e.g. casting): therefore, static mechanical properties (yield and tensile strengths) are often higher, while maintaining approximately the same ductility. This result can be found for example by comparing the static properties of wrought (ASTM A276) and additively manufactured (by LMD) 316L stainless steel (Carlton et al., (2016) and Wang et al., (2016)), of cast (EN 1706) and LBM AlSi10Mg aluminium alloy (Manfredi et al., (2014), of wrought (Donachie, (2000)) and LBM Ti-6Al-4V titanium alloy (Xu et al., (2015)).

Similarly to the static mechanical properties, structural durability is of major concern in design structural components. Therefore, a number of fatigue studies have been reported in the literature. As a general remark, microstructure, surface roughness and size/distribution of material defects strongly influence the fatigue strength. Generally speaking, additive manufacturing does not produce final parts because different degrees of post processing are required to achieve the target properties. Reduction of remaining porosity, mitigation of inner residual stresses, preparation of functional surfaces is often achieved by means of hot isostatic pressure (HIP), heat treatment, machining/micro-machining, surface treatments like sand blasting or micro-shot peening. Less fatigue studies are reported in the literature as compared to static strength studies (see for example the recent extensive review on additive manufacturing of metals by (Herzog et al., (2016)).