DYNAMIC MECHANICAL PROPERTIES OF HIGH SPEED SELECTIVE LASER MELTING AT 4.5KW

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ABSTRACT

Selective Laser Melting (SLM) is a promising manufacturing method for the production of components in the aerospace and other industries. This is due to the high complexities and ability of the machine to print difficult to manufacture materials such as Ti-6Al-4V. In high speed selective laser melting the higher laser power allows for processing at high speeds, thus ensuring a quick production time. However, the higher laser power affects the microstructure and mechanical properties of the produced specimen. Therefore, in this study, a 4.5 kW laser on the Aeroswift machine was used to produce specimen for fracture toughness and fatigue crack growth rate testing in the as-built condition. The results obtained are comparable to those of other SLM systems and poorer than conventional manufacturing methods while not far from adhering to aerospace client requirements.

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1. INTRODUCTION

Selective Laser melting is an additive manufacturing method that uses a laser to selectively fuse layers of metal powder into a solid 3D component [1-5]. The layer by layer approach gives the process advantages over conventional methods such as geometrical complexity, made to order components and short design and manufacturing times [1, 3, 5]. Inherent to the process are high temperature gradients resulting in rapidly solidified non-equilibrium microstructures and residual stress development [4, 5, 6]. The non-equilibrium microstructure and residual stress adversely affect static and dynamic mechanical properties of produced components. The benefit of SLM then, can only be realized when the mechanical behavior of the final product is at least able to be matched to conventionally produced components of the same material [1]. Process parameters such as scan strategy, energy density, scan speed and preheating can be optimized to produce competent parts [6]. Pre and post heat treatments can also be employed to relieve stresses and alter the microstructure for favorable mechanical properties.

The titanium alloy grade 5 (Ti6Al4V) has found great use in the aerospace industry for structural applications. It is titanium's high specific strength ratio that makes it attractive to the aerospace industry where light but strong components with good and high temperature corrosion resistance are required, [7].

The fracture mechanics of Ti6Al4V in SLM have been studied by a number of researchers, where the porosity, microstructure, residual stress, build direction and preheating have been shown to have a marked influence on fracture toughness and crack propagation [3-5]. Pores act as stress raisers in a component and promote crack initiation while a fine microstructure leads to a large number of grain boundaries acting as obstacles points for crack propagation [2, 4]. Residual stress influence crack growth while fracture toughness is improved by good ductility of the material [3]. The anisotropy in residual stress development makes build orientation an important consideration on both fracture toughness and fatigue crack growth rates [1,4,5]. The preheating temperature also impacts crack growth rates [5].

In this work, the fracture toughness and crack growth properties of as-built Ti6Al4V specimen produced on the Aeroswift machine are compared to the properties obtained from commercial SLM systems, conventional methods and aerospace industry specific standard.

2. METHODOLOGY

2.1 Materials

. The specimen were manufactured on the Aeroswift high speed Selective Laser Melting machine at the CSIR National Laser Center using TLS GmbH Ti-6Al-4V. The laser power used was 4.5 kW under an argon filled atmosphere and a preheating temperature of 200˚C. The densilty of the specimen was > 99.5%. Specimen were tested in the as built condition.The specimen were machined according to ASTM E399-17 for Fracture Toughness and ASTM E647-15 for Fatigue Crack Growth Rate. This direction is designated by the ASTM E399 standard and shown in figure 1. The specimen geometry only differs in the thickness B of the specimen. Fracture toughness specimen had a B= 10 mm while fatigue crack growth rate specimen had a thickness of B= 6 mm.

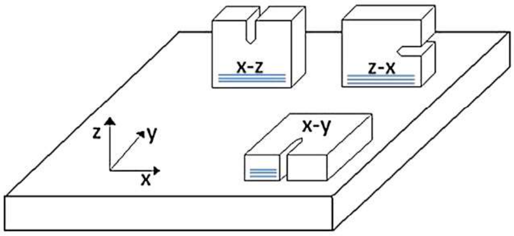

Figure 1: Specimen orientation and labelling according to ASTM E399-17 ,the lines represent successive layers [1].

2.2 Mechanical Properties Testing

The direction of the build was based on a previous study by Cain et al. [1] where the worst performing direction was ZX and is the direction of specimen used in this study. Fracture toughness and fatigue crack growth rate testing was carried out on a 30kN Instron 1342 machine. Fracture toughness testing was done according to ASTM E399-17, a pre crack of 7mm was introduced by reverse cyclic loading at 15Hz after which the fracture toughness was measured in tension. Fatigue crack growth rate testing was carried out according to the ASTM E647-15 standard, a1mm long pre-crack was developed and testing was done using a cyclic load in tension with R = 0.1 at a constant load. The Paris relationship (equation 1) is plotted to determine the Paris Constants for fatigue crack growth rate.

$$\frac{da}{dN} = C\ (\Delta K)^m \qquad \text{eq. 1}$$

where da/dN is the crack growth rate, ∆K is the stress intensity amplitude and C and m are material constants.

2.3 Metallography

The Jeol JSM-6110 plus Scanning Electron Microscope and the Olympus SZ40 Stereo microscope were used for metallographhic analysis.

3. RESULTS

3.1 Fracture Toughness

A microscopic study of the fracture surface was carried out using the SEM. Figure 1a shows the stereo microscope images of the fractured surface showing a classic thumbnail crack growth front. The SEM image in figure 1b showed dimples indicating ductile fracture of the surface. Some pores were also observed which could have impacted the fracture toughness negatively.

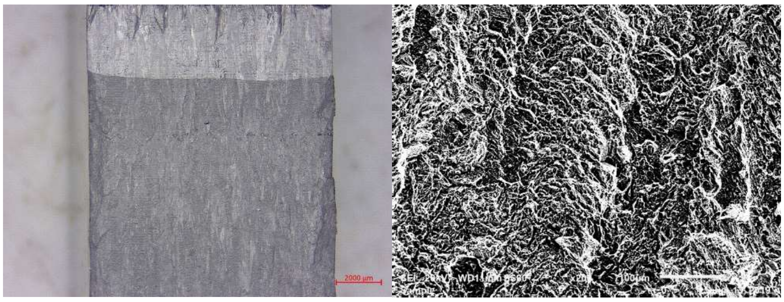

Figure1: Fracture surface a) A picture of the crack growth front under the stereo microscope X5 b) SEM image at X200 magnification

The fracture toughness results of the as-built specimen from the Aeroswift machine are presented in Table 1 and compared to those of commercially available systems, Airbus specifications and conventional manufacturing methods. While the Aeroswift specimen fracture toughness is lower than that of Vaccum Arc Remelted titanium, a conventionally manufacturing method, it is comparable to the Airbus standard and that of the work by Van Hooreweder [2]. However, the results obtained showed more crack growth resistance compared to It is much better than the result of Cain et al.[1].

Table 1: Fracture Toughness Results.

Manufacturing Method	K_{1C} *(MPa.m$^{1/2}$)*
Aero Swift	45.97±1.65
SLM Solutions - Cain et al.[1]	16.00±1
SLM Solutions -Van Hooreweder et al.[2]	52.40±3.48
Airbus Material Specification (AIMS)	50
Materials Handbook: Titanium [2]	64.9

3.2 Fatigue Crack Growth Rate

The Paris curve for the Aeroswift specimen is illustrated in figure 2. The ΔK threshold for this sample is 6.8 MPa√m which is comparable to values in literature [4]. The Paris constants for these specimen are C= $3x10^{-8}$ and m= 3.0521. Fast fracture occurs after a stress intensity factor of 30 MPa√m.

Figure 3 compares the Paris curve steady region crack growth of the Aeroswift produced specimen to those of conventional manufacturing methods, commercial systems and industry standard. The Vacuum Arc Remelting method [2] produces significantly better crack resistance than Aeroswift. The crack growth rates of the commercial SLM systems used by Cain et al.[1] and Van Hooreweder et al. [2] are noticeably slower than that of Aeroswift, while the crack growth rates of the commercial systems of Edwards et al. and Jiao et al. are comparable to the crack growth rates of the Aeroswift machine. Of great interest is the fact that the Aeroswift crack growth rate is slightly slower than required in industry by Airbus. The corresponding Paris equation constants for figure 3 are shown in table 2.

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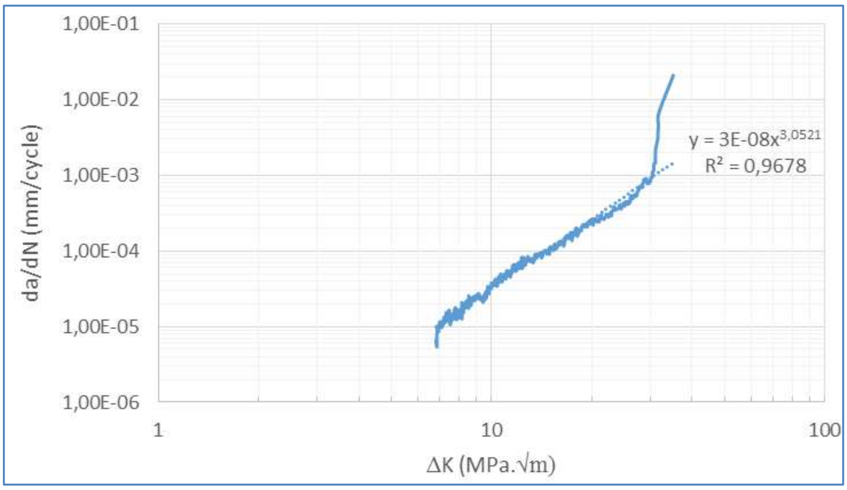

Figure 2: The Paris Curve for as-built Aeroswift specimen.

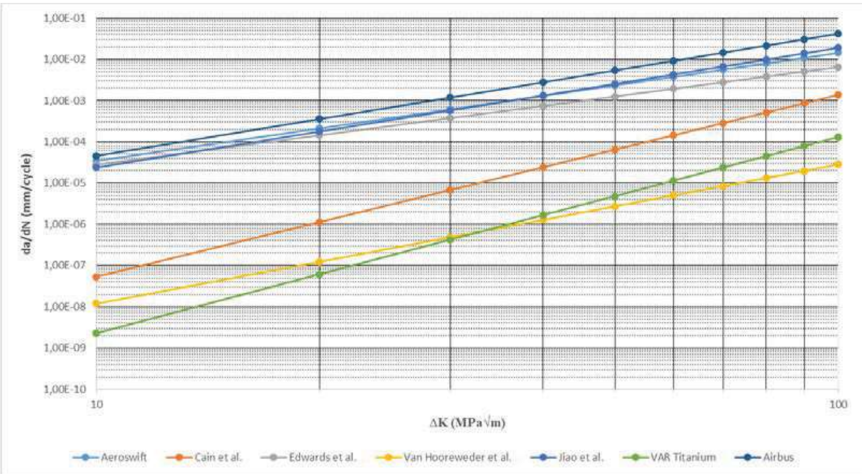

Figure 3: Steady state crack growth rate curves.

Table 2: Constants for the Paris equation.

	C	*m*
Aeroswift	3.0E-08	3.05
SLM Solution -Cain et al.[1]	2.08E-12	4.41
SLM SLM MTT250Edwards & Ramulu[4]	1.20E-07	2.37

BLT-S300 -Jiao et al. [5]	2.99E-08	2.9
K.U Leuven in-house machine -Van Hooreweder et al.[2]	5E-12	3.38

4. CONCLUSION

The fracture toughness and fatigue crack growth rates of specimen produced by the Aeroswift machine at 4.5kW were benchmarked against those of commercial systems found in the literature, conventional methods and industry standards. While the results vary when compared to different SLM commercial systems, the Aeroswift specimen dynamic mechanical properties are below conventionally manufactured methods but are comparable the aerospace industry requirement of AIMS in the as-built condition. Post build processing and preheating are available avenues to better these results and produce comparable propeties to those of convetional methods.

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