INFLUENCE OF STRESS RELIEVING THERMAL CYCLES ON AlSi10Mg SPECIMENS PRODUCED BY SELECTIVE LASER MELTING

Busisiwe J. Mfusi[1,2a], Ntombizodwa R. Mathe[1b], Patricia A.I. Popoola[2c] & Lerato C. Tshabalala[1d]

[1] National Laser Centre, Council for Scientific and Industrial Research, Meiring Naudé Road, Brummeria, Pretoria 0185, South Africa

[2] Chemical, Metallurgical and Materials Engineering Department, Tshwane University of Technology, Staatsartillerie Rd, Pretoria West, Pretoria, 0183

[a] mfusibusisiwe08@gmail.com*, [b] NMathe@csir.co.za*, [c] PopoolaAPI@tut.ac.za, ltshabalala1@csir.co.za

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Abstract: The AlSi10Mg alloy is known for its castability, corrosion resistance, high heat conductivity, low weight and good weldability. The applications of the aluminium alloy components includes heat exchangers that are subjected to high temperatures and corrosive environments. The production process of AlSi10Mg alloy using selective laser melting (SLM) has been extensively explored because of its hypoeutectic composition of Al and Si. However, it has been observed that stress relieve has a negative effect on tensile properties of SLM built samples, while retaining and improving ductility. Therefore, this study aims to investigate the thermal behaviour of AlSi10Mg alloy produced by SLM process with the specimen heat treated at 300°C for 2 hours. The specimens exhibited mass gain during the TGA (Thermalgravimetric Analysis) as a result of the precence of oxygen as one of the elements present as detected by the EDS analysis. The fatigue results post thermal treatment demonstrated improved fatigue resistance qualities comparable to casted AlSi10Mg.

1. Introduction

Conventional methods such as casting for component production are slowly being substituted by additive manufacturing (AM) methods which are currently under investigation especially in the production of complex structures [1]. As a category of the AM technology for the manufacturing of the metal components from powder, selective laser melting (SLM) makes an interesting study for aluminium alloys. These alloys are becoming the most desirable metals to different industries due to its properties such as low specific weight, high thermal and electrical conductivity, low power radiation, high plasticity and ductility, high weldability as well as toxicity [2].

AlSi10Mg as one of the composite matrix, is acquiring a reputation in the automobile, aerospace and rail applications to substitute the monolithic counterparts [3]. Components such as heat exchangers and propellers, which are used in numerous mechanical engineering systems have depended on conventional manufacturing methods for production which due to manufacturing confinements have affected the designs complexities [4] [5, 6]. These components can be produced by AM as an alternative manufacturing process. However, one of the main drawbacks of AM is the need for post built thermal treatment to relieve the inherent residual stresses.

In this case, the modifying of the mechanical properties of SLM materials by thermal treatment customarily follows the procedures that have been developed for conventionally manufactured materials [7]. Oxidation of aluminium alloys during AM processing was a perplexing discovery. This is because the oxygen in the chamber is capable of forming thin oxide films on the molten and solid material which may lead to porosity in the material [8]. Brandl et al. suggested that when aiming to increase fatigue resistance, combining different heating platforms and peak-hardening is a good idea [9-11]. Francolin et al. used thermal gravimetric analysis (TGA) to prove the negative effect of oxygen on physical and mechanical properties of scaffold sheets. However little information is available on the TGA analysis on SLM produced AlSi10Mg.
This study aims to investigate the thermal and fatigue behaviour of AlSi10Mg produced by selective laser melting. Since some components like heat exchangers are subjected to high temperatures and cycling, the kind of temperatures and fatigue conditions that these sample properties can withstand as well as the improvements that needs to be done will be studied.

2. Experimental Procedure

2.1. *Samples production*

The AlSi10Mg samples were built using the SLM Solutions M280, which is a commercial system with fixed parameters of; 150W power, 1000 mm/s scan speed, 50 μm hatch spacing and 50 μm powder layer thickness. These samples were built in three different directions namely, XY horizontal, 45° oblique and Z vertical, which were denoted batch A, batch B and batch C respectively [12]. The samples were stress relieved using a vacuum furnace at 300ºC for 2 hours and then examined for variations relative to as built samples. This heat treatment is taken directly from conventional technique.

2.2. Characterization

JEOL JSM 6010 Plus/LA, scanning electron microscope (SEM), fitted with Electron Diffraction Spectroscopy (EDS) detector, was used for EDX analysis at an accelerating voltage of 20 kV. The samples were sectioned, mounted, polished and etched using Keller's reagent prior to EDX characterisation. For thermal analysis, samples of 20 mg filings were prepared for the Perkin Elmer Pyris 1 TGA thermogravimetric analyser, under conditions of 50 to 900ºC at a rate of 10ºC/min for thermogravimetric analysis in a Nitrogen environment. The 20kN Zwick/ Roell Tensile tester was used applying standard ASTM 466 for fatigue cycle tests, with a load varied from 80 – 120 MPa, stress ratio of 0.1. The number of fatigue cycles ranging from 230 000 to 2 000 000 at the frequency of 10 Hz. The samples were stopped after 2 million cycles.

3. Results and discussion

3.1. Energy Dispersive Spectroscopy (EDS)

The EDS results presented in table 1 demonstrates the atomic percentages of the elements present in the samples. Some of the areas of microstructures also comprise of oxygen as one of the elements present in them. Louvis [8] attributed this as a result of a system chamber that is not completely oxygen free. This oxygen level of 0.1-0.2% is high enough to affect aluminium alloys [2] and capable of forming oxide layers on two different scanned tracks.

Table 1*: EDS results of the SLM produced AlSi10Mg samples showing atomic% of element content in each microstructure (AB-as-built, SR-Stress relieve)*

		ATOMIC %				
ELEMENTS	**A-AB**	**B-AB**	**C-AB**	**A-SR**	**B-SR**	**C-SR**
Mg	1.07	1.22	1.21	1.00	1.39	1.02
Al	89.9	92.14	92.14	85.10	89.53	89.47
Si	7.72	5.66	5.49	12.3	9.09	9.51
O	1.33	0.99	1.16	1.60	0.00	0.00
TOTAL	100.00	100.00	100.00	100.00	100.00	100.00

Figure 1 and 2 presents the EDS images and spectra respectively, of samples before and after stress relieving which were focused on certain areas of the microstructure at 60X and 500X magnification. It was observed that silicon is the second major element in all the samples. It was also observed that post thermal treatment there is an increase in silicon content which precipitate to the surface while aluminium decreased. This is because during the cooling and solidification, silicon contracted and during post thermal treatment, it precipitated as silicon and Mg_2Si [13, 14]. Aboulkhair [1], stated that during rapid cooling, α-aluminium is permitted to solidify first into a cellular structure while leaving the residual silicon to form at the grain boundaries. The silicon is only allowed to disperse during the coarsening of the microstructure subsequent to post thermal treatment.

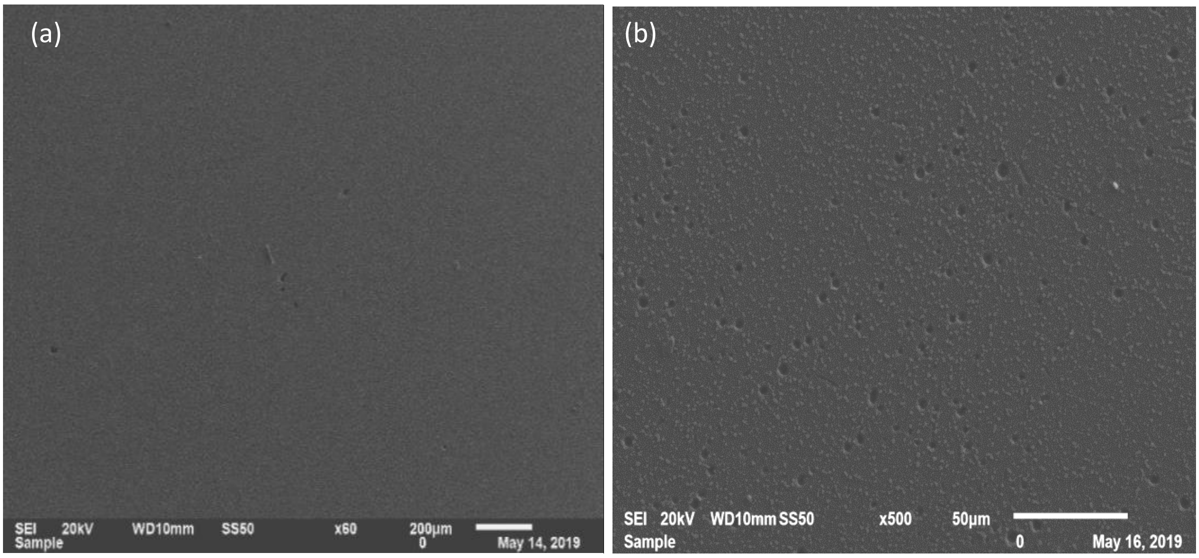

***Figure 1**: SEM-EDS area images of the SLM produced AlSi10Mg samples showing (a) 60X and (b) 500X magnifications*

Due to the higher electron backscattering coefficient, pores and oxide particles are easily distinguished from one another through the brightness threshold which makes oxide particles to appear brighter than pores [15]. In the figure 1b, silicon is observed to have precipitated to the surface after stress relieve.

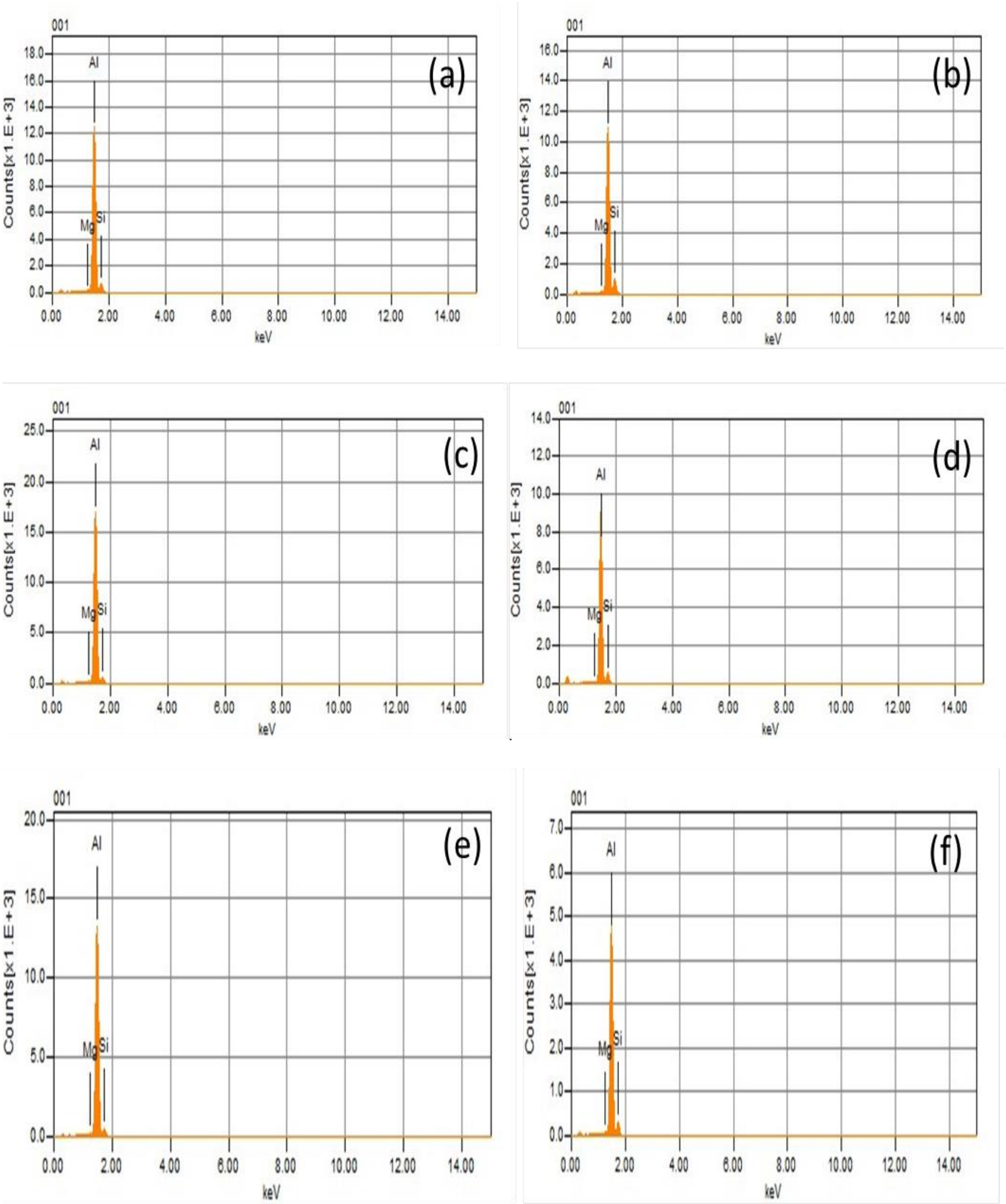

Figure 2: *SEM-EDS results of the SLM produced AlSi10Mg samples showing (a,c,e) as-built and (b,d,f) post thermal treatment*

3.2. Axial Fatigue

The stress relieved samples for batch A and C were further analysed for axial fracture toughness in order to determine the effect that the heat treatment process has on the properties. The results were compared to the literature data of AlSi10Mg and T6 heat treated AlSi10Mg, [16]. The results in this work are indicated in yellow showing the number of cycles as a function of the maximum stress. Comparing the obtained results with the literature values for SLM processed AlSi10Mg (red) and die-casted Al6061 that was T6 heat treated (blue). It was observed that the samples can withstand higher fatigues and are comparable to literature values of the same load [17]. Figure 3 presents the dog-bone samples used in this test and not all samples that actually fractured at 2000 000 during the test.

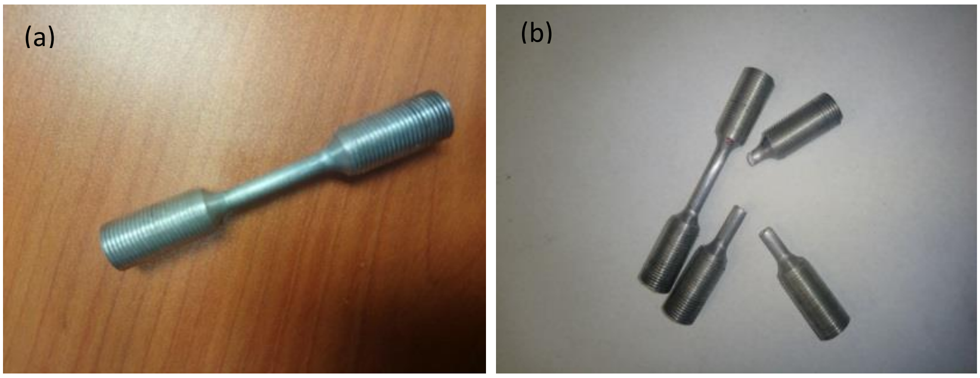

Figure 3*: (a) Dog-bone sample used for axial fatigue tests (b) Fractured fatigue samples after testing.*

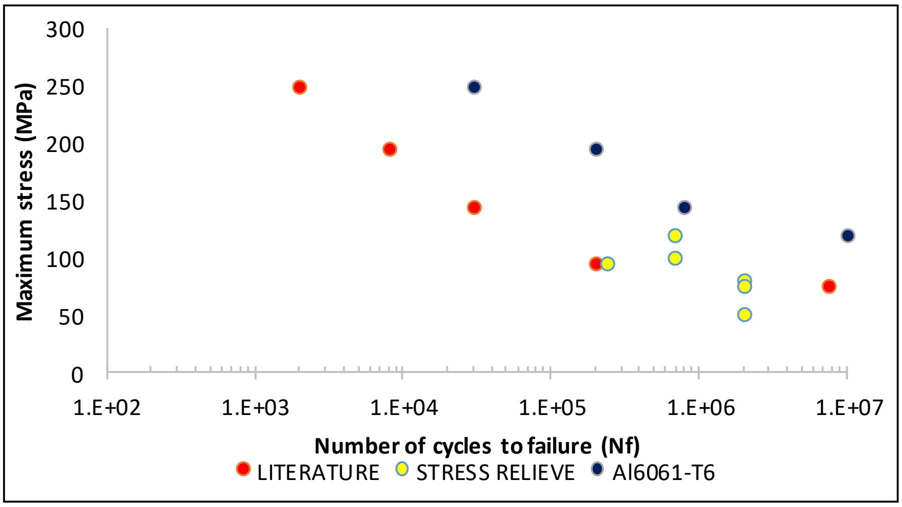

Figure 4*: Axial fatigue results of the SLM produced AlSi10Mg samples*

These results show that the even though the stress relieving profile used in this case resulted in a decline in strength, it increased the fatigue life of the samples. Most studies on fatigue life are based on the behaviour of cast aluminium alloys such as A360 which was believed to be affected by microstructural defects such as porosity, spacing of cellular and dendrite arms as well as grain size and inclusions [9, 15, 18]. Major and serious fatigue cracks found at the tail of the defect size distribution are found to be the cause of failure in die-casting [19], whereas with AM components defects that lead to probable fractures are generally caused by oxide films. Alumina is easily formed as oxide film on the powder particles since aluminium has a great affinity to oxygen. The residual porosity exposed on the surface of the component is the substantial to dictate of fatigue life for SLM produced AlSi10Mg [15].

3.3. Thermogravimetric Analysis (TGA)

Presented in Figure 4 are the TGA results of as-built and post heat treatment samples. In the Figure 3a, the anisotropy in build direction is observed in the variation of the graphs. The as-built thermal behaviour of orientation B stands out from A and C in the range of temperatures between ambient and 400ºC, it shows weight loss which is associated with the defects observed in the fractography structures of this work. It is anticipated that the bolos defects began decomposing. At 595ºC all the specimens loose mass due to melting, which is the melting point of aluminium. In the post stress relieving graph presented by Figure 3b, no variation in orientation is observed subsequent to thermal treatment which made all the structures homogeneous. Overall, all the graphs show mass gain post melting point as result of oxidation. Oxygen was picked up to be present in the sample structures by the EDS analysis as explained above. The specimen must have gained weight due to aluminium reacting with oxygen and forming aluminium oxide as Tang stated the high affinity they have to one another [15]. In this case, the AlSi10Mg can withstand operational conditions of temperatures above its melting point of 595ºC due to the reaction of aluminium with oxygen to form aluminium oxide which melts at 2072 ºC [15].

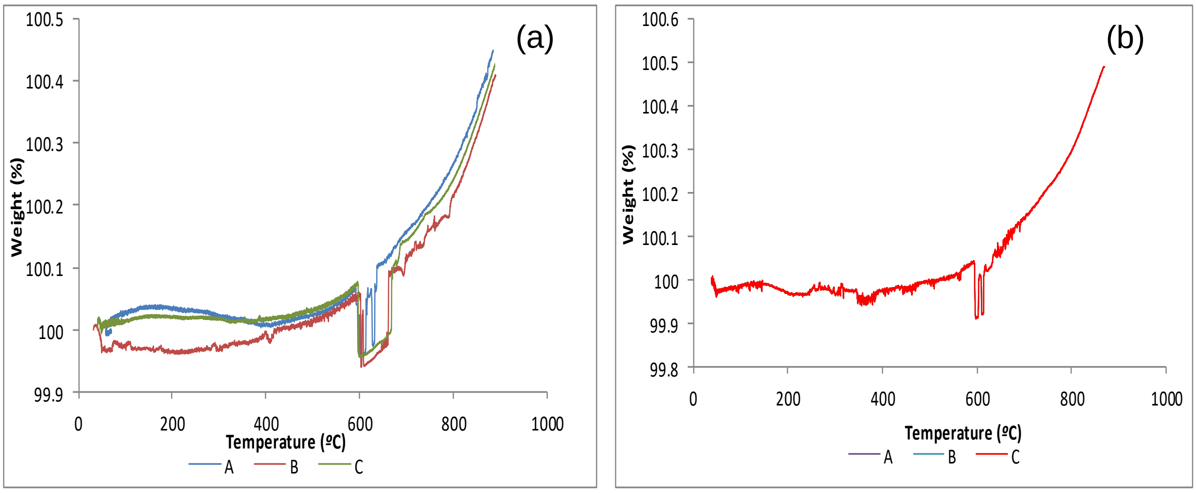

Figure 4: *TGA results of the SLM produced AlSi10Mg samples showing (a) As-built and (b) Post thermal treatment*

4. Conclusion

The thermal behaviour of the SLM produced AlSi10Mg changes with the post build stress relieving and has shown a dependence on the build direction. In this case, the presence of oxygen content in the microstructure as observed through EDS, contributed a positive influence on the TGA results of SLM produced AlSi10Mg components. It can thus be concluded that as long as the oxide film is not exposed on the surface of the SLM produced AlSi10Mg samples, it can result with the improvement of fatigue life, especially after heat treatment where the residual stresses are modified.

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