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The effect of atmosphere on the structure and properties of a selective laser melted Al–12Si alloy

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ABSTRACT

Al–12Si components were manufactured by Selective Laser Melting (SLM) using three different atmospheres: argon; nitrogen and helium. The atmosphere type did not affect the part's *density or hardness* and all components reached near full relative density (> 97%). The mechanical properties of the components produced in Ar and N_2 were superior to those in He, especially the ductility, which has been attributed to the formation of pore clusters in the microstructure. The mechanical properties in SLM-produced components are superior to those produced using conventional method.

1. Introduction

Aluminium and its alloys are widely used in engineering structures and components because of its light weight and high corrosion resistance. Traditional fabrication methods of aluminium components such as casting, forging, and extrusion require tooling or dies to shape the parts. These are relatively expensive and time-consuming to produce, especially for small production runs of complex parts. Indirect rapid manufacturing of aluminium components is possible, but requires a two-stage process of green part production followed by infiltration [1]. It therefore takes 2–3 days to produce a part. There are other indirect methods but they typically require the production of a lost wax model and subsequent investment casting, which is not a true rapid manufacturing technology as it still requires the fabrication of a mould. More recently, the production of aluminium components directly from a computer model has become possible through a process known as Selective Laser Melting (SLM) [2–9]. During the SLM process, a high intensity laser beam selectively scans a thin powder bed, melting the metal particles which solidify to form a solid layer. The build platform then moves down by the thickness of one layer (typically 50–100 μm), a new layer of powder is deposited on the top and the process continues until the part is complete. One of the key advantages of SLM is its ability to produce near need for any tooling or machining [1,10–12]. For the SLM of aluminium, work has concentrated on the processing of an alloy commonly refered to at AlSi10Mg (nominal composition Al–10 wt% Si–0.4 wt% Mg) [2,3,6–9], which is equivalent to the casting alloy A360.0 [13]. There has been considerably less work published on Al–12Si and 6061 [4,5], both of which reported low densities.

Selective Laser Melting is a complex physical metallurgical process, involving many parameters (typically including scanning speed, laser power, scan spacing, layer thickness, and scanning strategy), and it therefore requires a comprehensive understanding of the effect of these for optimal manufacturing. Considerable effort has been expended on a wide range of materials (including aluminium) to optimise the parameters with the aim of improving density (see for example, [4,5,11,14,15]) and surface quality/roughness [8,11,16,17]. In addition, the build orientation has been shown to have an effect on the properties of SLM produced parts, with the vertical (build) direction resulting in the lowest properties [6,18,19]. Among all the processing parameters, the effect of laser scan speed, laser power, layer thickness has been the most widely studied. In contrast, there has only been a small amount of work focused on the effect of atmospheric oxygen content on the quality of laser melted parts [20]. For the processing of Al-based alloys, the atmosphere used has been either Ar [2,4–7] or not stated [3,8,9]. Hence it is apparent that role of the atmosphere type has not been studied in detail.

During the conventional press-and-sinter processing of metals, the atmosphere is often reactive and used for such purposes as oxide reduction and binder/lubricant removal [21]. For the sintering of aluminium, it is generally considered that a nitrogen atmosphere is more effective for densification than other atmospheres [22,23].

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This has been attributed to the reaction of the Al with the nitrogen to form aluminium nitride [22–25]. However, little has been reported on the role of the atmosphere during Selective Laser Melting. In this work, we have reported that the atmosphere type has essentially no effect on the densification process during Selective Laser Melting but does have some effect on the mechanical properties of the resultant parts.

2. Experimental

The details of the Al–12Si powder used in this work are summarised in Table 1. The composition of the powder was measured using inductively coupled plasma atomic emission spectroscopy (Spectrometer Services Victoria, Australia). Flowability and apparent density was measured according to Metal Powder Industries Federation Standards 03 and 04 [26], respectively. Nitrogen content of laser melted parts was measured using Leco nitrogen analysis (Spectrometer Services Victoria, Australia). Three samples from each atmosphere were analysed. The particle size was measured using a Malvern Mastersizer Plus. A scanning electron image (Tescan Vega3) of the powder, Fig. 1, shows that it is almost spherical in shape, and contains significant numbers of satellites. Selective Laser Melting was performed on a Realizer SLM 100 (ReaLizer GmbH, Germany). Prior to building the chamber was purged with either argon, nitrogen or helium atmosphere until the oxygen content was $<0.1\%$. In all the cases, the gases were of high purity, containing <10 ppm O_2. During building, a slight positive pressure of 10–30 mbar was maintained inside the chamber. Cubes with dimension of $10\times10\times10\ \text{mm}^3$ were manufactured using a laser power (at the part bed) of 200 W ($\lambda=1.06\ \mu$m), laser beam diameter of 35 μm, laser scan speeds between 375 and 2000 mm s^{-1}, and hatch spacing (distance between scan lines) of 0.15 mm. Parts were built by scanning the laser across the surface in 3 mm stripes. The direction of scanning was rotated through 90° between successive layers. The layer thickness was kept constant at 50 μm. Density was measured using Archimedes′ method, following Metal Powder Industries Federation Standard 42 [26], and is presented as a percentage of the theoretical density (2.65 g/cm^3). For each condition, three specimens were measured and the results averaged. The microstructure of the *XZ* (vertical) section was examined by mounting the samples in epoxy and polishing using standard metallographic techniques. Optical microscopy was performed on unetched

Table 1
Summary of the characteristics of the Al–12Si powder.

Composition (wt%)				Particle size (μm)			Flowability (s/50 g)	Apparent density (%)
Al	Si	Fe	Cu	d_{10}	d_{50}	d_{90}		
Bal	12.2	0.12	0.003	27	38	51	21.0	55.8

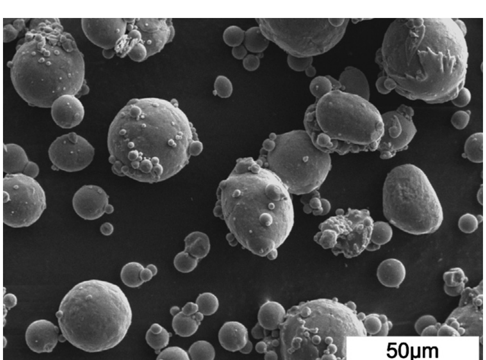

Fig. 1. Scanning electron micrograph of the Al–12Si powder used.

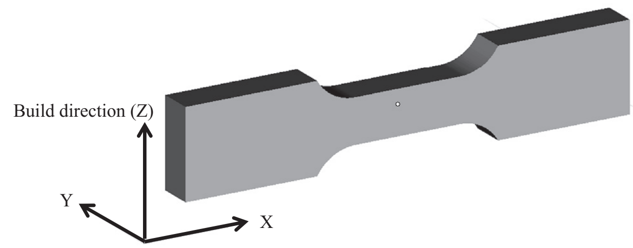

Fig. 2. Orientation of the tensile bar relative to the building direction.

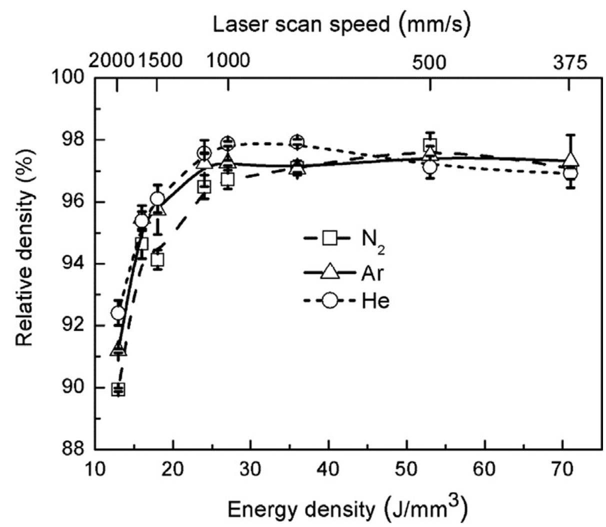

Fig. 3. Relative density of the SLM-produced Al–12Si samples as a function of incident laser energy. There is a general trend of increasing density with laser energy density, up to ~30 J/mm^3, after which the density plateaus. There is no significant difference between the three atmospheres. Individual points are an average of 3 tests and error bars show one standard deviation.

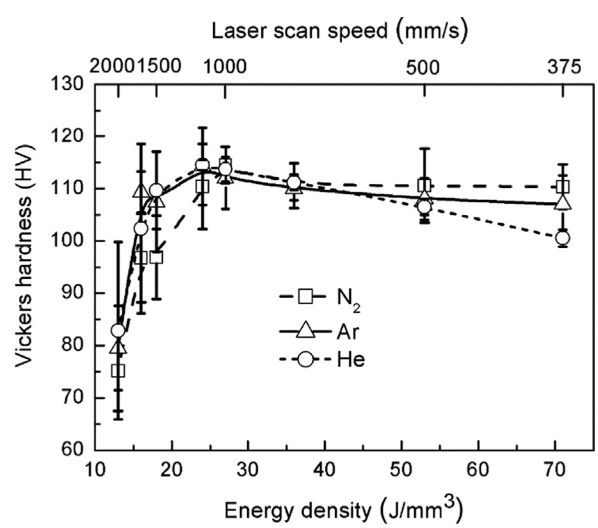

Fig. 4. The effect of laser energy density on the hardness of SLM-produced Al–12Si in Ar, N_2 and He atmospheres. Similar to Fig. 2, the hardness increases with energy density and there is no significant difference between atmospheres. Individual points are an average of 12 tests. Error bars show one standard deviation.