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2016

Yap, C. Y., Chua, C. K., & Dong, Z. L. (2016). Preliminary Investigation On Selective Laser Melting Of Pure Tin. Proceedings of the 2nd International Conference on Progress in Additive Manufacturing (Pro-AM 2016), 409-414.

https://hdl.handle.net/10356/84350

PRELIMINARY INVESTIGATION ON SELECTIVE LASER MELTING OF PURE TIN

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ABSTRACT: Selective Laser Melting is a 3D printing method that uses high power laser to melt selective regions of a powder bed and fabricate components layer-by-layer. It is capable of producing near full density components with metals. Tin is a low-cost metal with good corrosion resistance and a low melting temperature. However there has been no reported studies on SLM processing of tin. In this paper, a preliminary study on SLM of tin is carried out. The parameters were as such: scanning speed of 3,000 mm/s, layer thickness of 0.05 mm, laser power from 100 W to 200 W and hatch spacing from 0.1 mm to 0.2 mm. Relative density of 99.9 % was obtained.

KEYWORDS: Selective laser melting, 3D printing, Additive manufacturing, Rapid prototyping, Powder bed fusion

INTRODUCTION

Selective Laser Melting (SLM) is an Additive Manufacturing (AM) technology that is gaining popularity due to its ability to fabricate near full density metallic components without the need for post processing (Chua and Leong 2014). In recent years, industrial interest in direct manufacturing with AM is evident in the increase in global revenue for AM products and services. AM metals increased by 50 % in 2014 to 48.7 million USD and made up 42.6 % of the total products and services revenues from AM, previously dominated by polymer-based materials (Wohlers 2015). AM of metals is a sector predicted to continue a high pace of growth as the technology matures.

The SLM process is carried out in an enclosed chamber with a platform movable in the z-axis. It starts with coating a thin layer of powder on a substrate plate. A high power laser is then deployed to melt selective areas according to computer aided design (CAD) data which has been pre-processed into scanning vectors information for individual layers. Once the first layer has been

Proc. of the 2nd Intl. Conf. on Progress in Additive Manufacturing
Edited by Chee Kai Chua, Wai Yee Yeong, Ming Jen Tan, Erjia Liu and Shu Beng Tor

Published by Research Publishing, Singapore
ISSN: 2424-8967

processed, the platform lowers by a pre-determined distance (20 – 100 μm) and a new layer of powder is coated on to the preceding layer (Yap, Chua et al. 2015). The laser is deployed again to process the second layer. This combination of platform lowering, powder coating and laser scanning is repeated until the desire components are completely fabricated.

At the present moment, SLM is commonly applied in the biomedical, aerospace and automotive industries. The flexibility of SLM allows for fabrication of prostheses or implants that are customized to individual patients (Warnke, Douglas et al. 2008, Murr, Quinones et al. 2009, Jardini, Larosa et al. 2014), and building of bespoke aircraft components that are designed for functionality and weight savings (Airbus 2014). In order to increase the utility of SLM, research studies has been carried out to investigate the optimal process parameters for many different metals and alloys. Materials studied include 316L stainless steel (Spierings, Herres et al. 2011), M2 tool steel (Liu, Zhang et al. 2013), EH36 high strength steel (Wu, Tor et al. 2015), AlSi10Mg aluminum alloy (Loh, Liu et al. 2014), Ti6Al4V titanium alloy (Yadroitsev and Yadroitsava 2015) and even shape memory alloys (Khoo, Teoh et al. 2015).

Tin is a metal known for its low melting point of 505 K, with a density of 7.3 g/cm^3 in the β-phase. Hence, it is widely used as a solder in the form of Sn-Pb alloy. Tin is also corrosion resistant and is often used in plating to protect iron based alloys that would rust easily otherwise. As a metal by itself, tin is used to make decorative housewares such as punched tin lanterns. Although tin has low melting point and is easily processed compared to other metals and alloys, there has been no research on the AM of tin. In this study, SLM processing of tin was investigated and process parameters were optimized to fabricate near full density samples.

EXPERIMENT

Powder Material

Tin powder used in this study is supplied TLS Technik GmbH and has spherical morphology as shown in Figure 1. The powder has a D90 of 45 μm and a settled apparent density of 3.48 g/cm^3. Energy-dispersive X-ray spectroscopy showed that the powder material has a purity of 99.8 %.

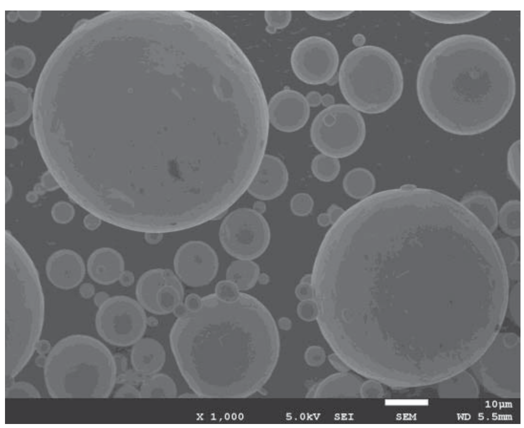

Figure 1 Scanning electron microscopy imagery of tin powder shows spherical morphology with relatively smooth surfaces.

SLM 250 HL

The SLM machine used in this study is the SLM® 250 ^{HL} manufactured by SLM Solutions GmbH. It is equipped with a Yb:YAG fiber laser with a wavelength of 1.06 µm. The exposure of laser on to the powder bed is controlled by an optical system of mirrors and an F-theta lens. The laser has a Gaussian energy distribution profile, a maximum power of 400 W and a standing spot size of 80 µm. The building chamber is flushed with argon gas until the oxygen level in the chamber is lower than 0.2 % before the fabrication process starts. This is to minimize the oxidation of metals at elevated temperatures.

Experimental Procedure

The main user-control parameters of the SLM process are laser power (P), laser scanning speed (v), hatch spacing (h) and layer thickness (t) (Yap, Chua et al. 2016). This investigation was carried out at a fixed scanning speed of 3,000 mm/s and a fixed layer thickness of 50 µm. Laser power was varied from 100 W to 200 W and hatch spacing ranged from 0.1 mm to 0.2 mm. Samples of 10 mm × 10 mm × 10 mm were built and their densities were determined via the Archimedes' principle. 5 sets of samples were produced for this study.

RESULTS AND DISCUSSION

Relative density refers to the ratio of the density of the sample over the theoretical density of the material. In this study, the density of tin is taken to be 7.298 g/cm^3 based on ASM Handbook Online™. Near full density tin samples were achieved in the study. Figure 2 illustrates the change in relative density of the samples with changes in laser power. The average relative density increased with laser power from 100 W to 160 W. However, it started to decrease after 160 W. Moreover the spread of results at 100 W and 120 W are relatively large, at 4.3 % and 2.2 % respectively. For instance, at 100 W, relative density of the SLM tin samples ranged from 92.9 % to 99.6 %. From 140 W to 200 W, the variations are less than 0.5 %. Figure 3 shows how relative density varies with hatch spacing. High relative densities were obtained from 0.1 mm to 0.14 mm and the mean values decreased from 0.16 mm onwards. However, the variations at hatch spacing of 0.16 mm to 0.2 mm are larger than 2 %.

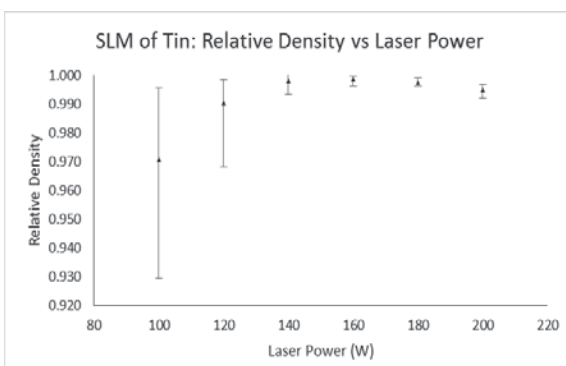

Figure 2 SLM of tin: relative density vs laser power.

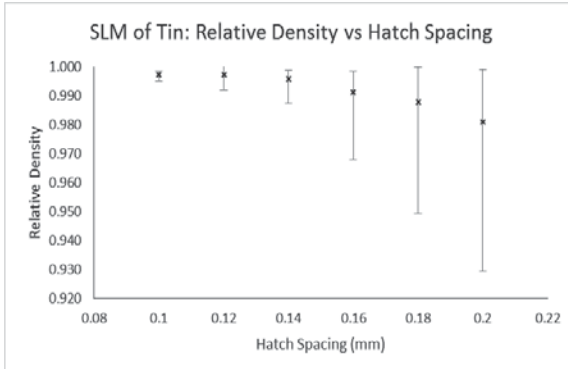

Figure 3 SLM of tin: relative density vs hatch spacing

The SLM process can be controlled by varying four parameters: laser power (P), scanning speed (v), hatch spacing (h) and layer thickness (t). These four factors can be combined to form a single variable (Krakhmalev and Yadroitsev 2014) during analysis as shown by equation (1):

$$VED = \frac{P}{v \cdot h \cdot t} \quad (1)$$

This combined variable gives an indication of the energy required to process the material during SLM When analyzed against VED values (Figure 4), it shows a clear trend that 99.9 % relative density can be obtained for VED as low as 5.2 J/mm^3. At low VEDs between 3 J/mm^3 and 5 J/mm^3, the relative density increases rapidly with VED values. For VEDs between 5 J/mm^3 and 7 J/mm^3, SLM samples obtained had near full density. At VED values larger than 8 J/mm^3, the variations in relative densities obtained become increasingly larger, indicating a drop in the reliability of the processing of tin. High energy density could lead to unstable melt tracks and vaporization of materials and inconsistent porosity in the SLM component. The most consistent results were obtained at about 6 J/mm^3.

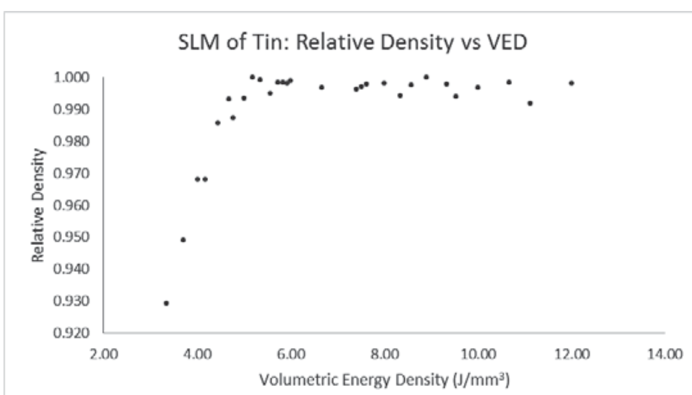

Figure 4 SLM of tin, plot of relative density vs volumetric energy density of the SLM process.

Table 1 Thermal properties of tin and common SLM materials.

Material	Tin	316L Steel	Ti6Al4V	AlSi10Mg
Density (g/cm^3)	7.298	8.00	4.42	2.63
Melting temperature / liquidus temperature (K)	505	1783	1933	925
Specific heat (J/g·K)	0.222	0.5	0.57	0.963
Latent heat of fusion (J/g)	59.5	-	-	-

In comparison with common SLM materials such as 316L stainless steel, Ti6Al4V and AlSi10Mg, tin requires very low VED values to achieve near full density parts. This is due to tin's relatively low melting temperature of 505 K and low specific heat. Table 1 compares the density and thermal properties of tin to other commonly used alloys in SLM. Such a low energy require would require careful control of the process parameters so as to prevent vaporization of materials during the SLM process, which would lead to highly unstable melt pool, loss of material low resultant density. Excessive heat could also lead to keyhole effect (Krakhmalev and Yadroitsev 2014), which introduces pores that are trapped in the components.

However, SLM of tin has some advantages compared to other high-melting temperature materials. As the melting temperature of tin is low, thermal fluctuation in the SLM process is also reduced. Hence, SLM processed tin would have a much lower residual stress compared to its steel and Ti6Al4V counterparts. Further studies are required to verify the residual stress in SLM tin components and their mechanical properties such as tensile strength, hardness and fatigue strength to path way for application of tin processed via SLM.

CONCLUSION AND FUTURE WORK

This paper reports the first study on SLM of tin. It has shown that SLM processing of tin is feasible and near full density components can be achieved. Samples with 99.9 % relative densities were successfully obtained with processing energy density as low as 5.2 J/mm^3. Further investigation such as microscopy, X-ray diffraction and micro-indentation tests will be carried out to examine the microstructure, crystal phases and mechanical properties of SLM tin.

ACKNOWLEDGMENTS

The authors would like to acknowledge Energy Research Institute @ NTU and Interdisciplinary Graduate School for the scholarship and National Research Foundation for funding the studies.

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