POROSITY DEVELOPMENT AND CRACKING BEHAVIOR OF Al-Zn-Mg-Cu ALLOYS FABRICATED BY SELECTIVE LASER MELTING

Ting Qi*, Haihong Zhu*, Jie Yin*, Baijin Chen†, Zhiheng Hu*, Xiaoyan Zeng*

* Wuhan National Laboratory for Optoelectronics, Huazhong University of Science and Technology, Wuhan, PR China
† State Key Laboratory of Material Processing and Die and Mould Technology, Huazhong University of Science and Technology, Wuhan, PR China

Abstract

Selective laser melting (SLM) of the 7xxx series Al alloy (Al-Zn-Mg-Cu) faces more challenge than other series aluminum alloy such as Al-Si system because of the high hot-cracking sensitivity. The porosity development and crack behavior of Al-Zn-Mg-Cu alloys fabricated at various scanning speeds in SLM process, as well as the influence of molten pool geometry were systematically investigated in this paper. Results show that the relative density over 99% can be achieved when the applied scanning speed is 150 mm/s. However, cracks are observed in almost all the as-deposited samples. The morphology, distribution and density of cracks were varied with the different molten pool geometry and scanning speed.

Introduction

7xxx series Al alloys are characterized by high tensile strength (over 500Mpa), high corrosion resistance and good fatigue properties [1-2]. These characteristics make over 85% of the 7xxx series Al alloys to use in automotive and aerospace fields. With the development of automotive and aerospace fields, the need for integral component of 7xxx series Al alloys is increased. The convention processing techniques encounter many difficulties due to the complexity and thin-wall structure of integral component. Hence, new manufacturing process like SLM is inevitable to enhance the process. SLM is an addictive manufacturing process with a high potential for producing complexly shaped components [3-4].

Because of the high thermal conductivity, poor fluidity and easy oxidized of aluminum alloy, up to now, only casting AlSi10Mg [5-8] and Al-12Si [9-11] have been widely manufacturing by SLM due to the weld ability and flow behavior. Few works have been focus on other aluminum alloys [12] especially the 7xxx series Al alloy. So far, Kaufmauu et al. [13] fabricated EN AW 7050 alloy sample with a relative density over 99%. However, all samples exhibited cracks. Sistiaga et al. [14] obtained crack free Al7075 alloy samples by adding 4% silicon in SLM process. Wang et al. [15] reported that an Al-Zn-Mg-Cu alloy with high zinc was successfully produced by SLM. The hardness of the synthesized SLM samples was higher than the corresponding T6 cast samples after heat treatment.

The present work investigated the feasibility for fabricated full dense Al7050 alloy. The morphology, distribution and density of cracks were also discussed under different scanning speed and molten pool geometry.

Materials & Methods

Al7050 cube specimens were fabricated by a self-developed SLM system with a continuous wave IPG YLR-200 fiber with maximum laser power of 200W [14]. The H_2O and oxygen level within the chamber was monitored to be kept below 50 and 30 ppm, respectively. The powder was gas-atomized with spherical morphology and a particle size distribution of d_{50} being 18.5 μm as shown in Fig.1. The chemical composition (wt. %) of the metal powder was 5.81 Zn, 2.04 Mg, 2.2 Cu as analyzed by inductively coupled plasma atomic emission spectrometry (ICP-AES).

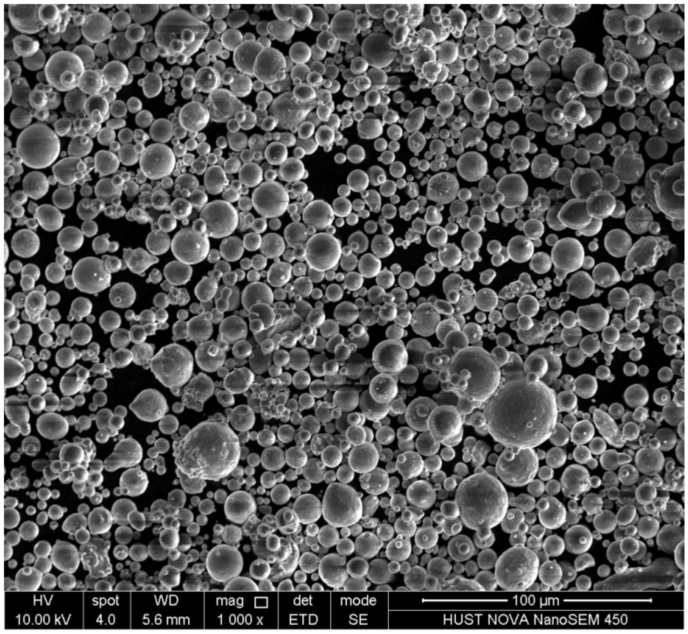


Fig. 1. SEM images of powder material Al7050 alloy

A layer thickness of 0.02mm, a laser power of 197W and a hatch distance of 0.1mm were used in producing the specimens. The scanning speed was varied between 150 and 1100 mm/s. The porosity of the specimens was optically measured with EPIPHOT-300 microscope [11]. The specimens were cross-sectiond and polished. The polished specimens were etched using Keller reagent to observe the microstructure by environment scanning electron microscope (Philips Quanta 200 ESEM).

<u>Results & Discussions</u>

Porosity

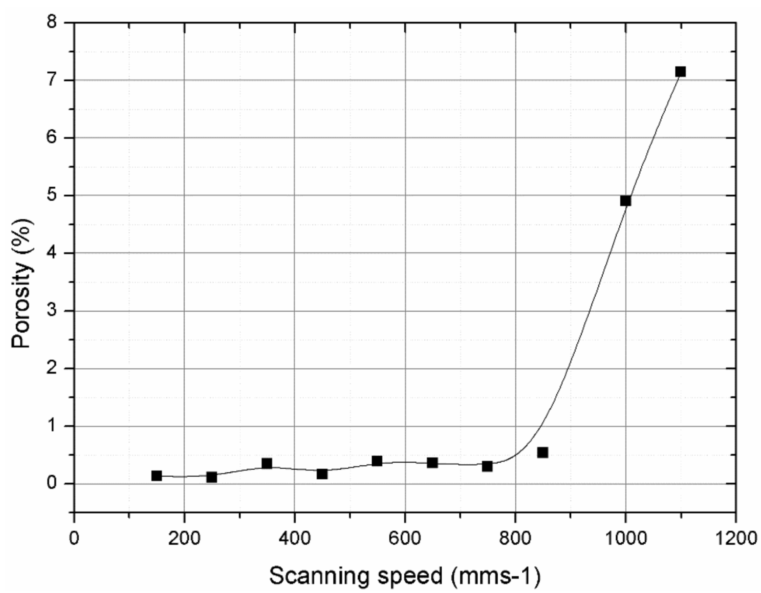


Fig.2 Effects of scanning speed on porosity of selective laser melted Al7050

Fig.2. shows the porosity of SLMed Al7050 at different scanning speed. The porosity reaches a minimum at the scanning speed of 150mm/s. The porosity slowly increases with increasing scanning speed in

the range of 150mm/s ~ 850mm/s. If the scanning speed is further increased the porosity is significantly increased.

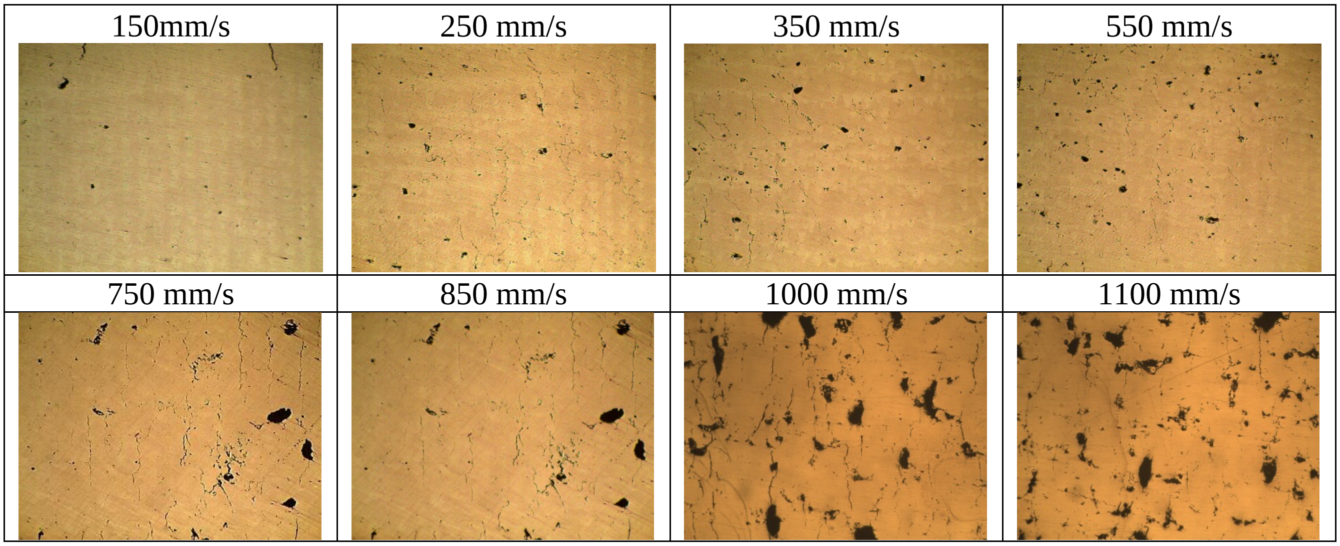


Fig.3. Microscopic cross-section images of Al7050 alloy with various scanning speed

Microscopic cross-section images of samples are exemplified in Fig.3. The images confirm the results shown in Fig.2. Small pores are formed and increased with scanning speed in the range of 150mm/s ~ 550mm/s. However, when laser scanning speed is above 650 mm/s, the laser energy per unit length is not sufficient to produced full dense specimens and the amount of imperfections is increased with the increasing of scanning speed.

Crack

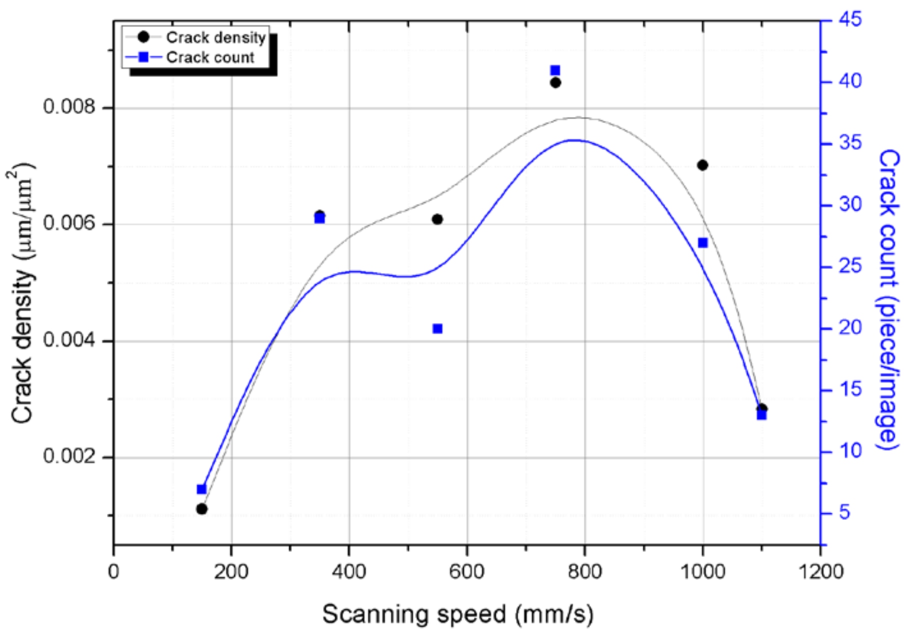
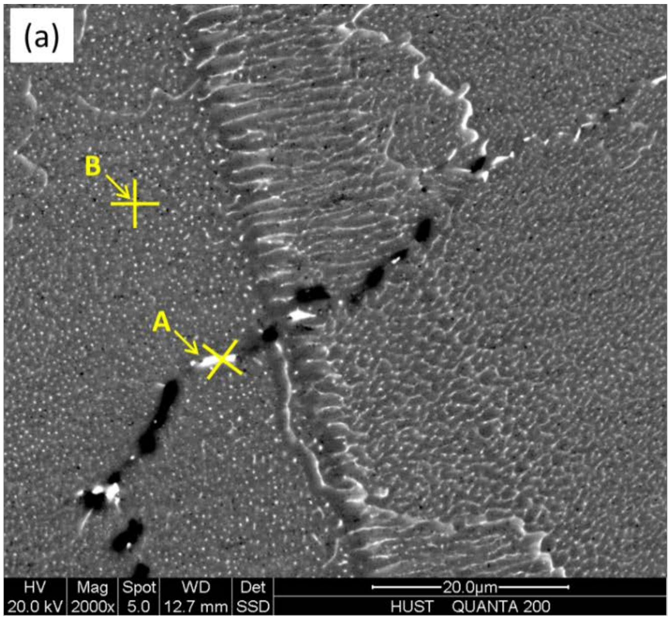


Fig.4. Crack count and density of SLMed Al7050 alloy deposited at various scanning speed

The crack count and crack density defined as the total number and length of cracks (μm) per unit area are counted to evaluate the cracking sensitivity [15]. Fig. 4 shows crack count and crack densities of the SLMed samples deposited at various scanning speed. Unexpectedly, cracks are observed in all the samples. When the scanning speed of 150 mm/s is applied, the lowest cracking sensitivity obtained in the work is the crack count of 7 piece/image and crack density of 1.1×10^{-3} μm/μm² on cross section. There is a downward trend in crack count and density as laser scanning speed from 150 to 1000 mm/s. Meanwhile, the porosity is increased (Fig. 2) and the crack count and density is decreased dramatically (Fig. 4) at the scanning speed of 1000 mm/s. The residual stress in specimen is released with the increasing of porosity. Thus, at the scanning speed of 1000 mm/s, the low level of residual stress is not suitable to promote the crack growth. The optimization of scanning speed is crucial to achieve low cracking sensitivity of the SLMed Al7050 alloy.



(b)

	Position A	Position B
Element	Wt%	Wt%
MgK	01.43	01.18
AlK	83.64	94.74
CuK	10.57	02.20
ZnK	02.51	01.24

Fig.5. (a) SEM image of the SLMed samples, (b) EDS result of position A and position B in (a)

The microstructure of SLMed sample at scanning speed of 150 mm/s is investigated (Fig. 5a). Fine equiaxed grain structure and cellular dendrite structure are existed in the melt pool. The solidification morphology is dependent on the radio of the thermal gradient and growth rate [6]. The chemical composition at propagation site of the crack (Position A) and matrix (Position B) are investigated by energy dispersive spectroscopy (EDS). It can found that the Cu element concentrates in the crack and may promote the forming of low-melting eutectic compositions. The low-melting eutectic compositions constitute liquid films in the grain boundary. When the the liquid film is torn by stress, the opening of crack tip is easily to be promoted. ,

<u>Chemical composition and hardness</u>

In Table 1, the chemical composition for the utilized powder and fabricated samples with different molten pool geometry is listed. The results show that the Zn contents of fabricated samples are lower than the utilized powder due to the evaporation of Zn. The Zn content in samples with shallow molten pool is little higher than the sample with deep molten pool.

Element	SLMed specimen with deep molten pool (wt. %)	SLMed specimen with shallow molten pool (wt. %)	Powder (wt. %)
Zn	1.277	3.71	9.34
Mg	1.563	2.037	2.21

Table1 EDS results of the SLMed specimens with different molten pool geometry

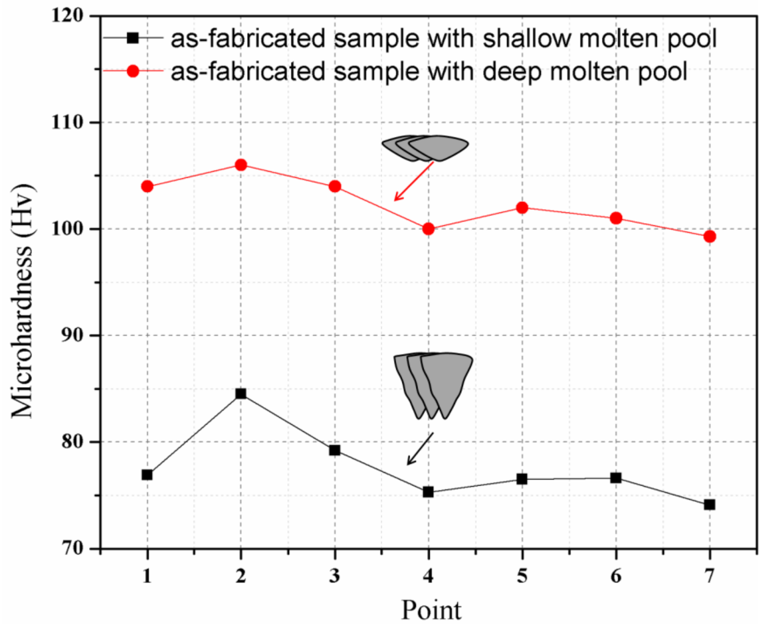


Fig. 6 Microhardness of SLMed Al7050 samples with different molten pool geometry

Fig. 6 demonstrates the microhardness measurements on SLM produced parts with different molten pool geometry. Due to the variation in chemical composition between the shallow molten and deep molten pool, the microhardness of as-fabricated sample with shallow molten pool is higher than the sample with deep molten pool.

Conclusions & outlook

Effect of scanning speed on the porosity development and crack behavior of SLM produced Al-Zn-Mg-Cu alloys is investigated. The relative density over 99% can be achieved when the applied scanning speed is 100 mm/s. However, cracks are observed in almost all the SLMed 7050 Al alloy samples. The cracking sensitivity firstly increases and then decreases with increasing scanning speed. The microhardness of as-fabricated sample with shallow molten pool is higher than the sample with deep molten pool. Thus, the loss of Zn element acts a significant role in determining the microhardness of SLMed samples.

Acknowledgements

This research is supported by the National Natural Science Foundation of China (61475056) and the National Program on Key Basic Research Project of China （613281）. The authors would also like to thank the help of the SEM analysis by the Analytical and Testing Center of HUST.

Literature

[1]Jr, E. A. Starke, and J. T. Staley. "Application of modern aluminum alloys to aircraft." Progress in Aerospace Sciences 32.2(1996):131-172.

[2] Fridlyander, I. N, and O. G. Senatorova. "Development and Application of High-Strength Al-Zn-Mg-Cu Alloys." Materials Science Forum 1996:1813-1818.

[3] Li, Xiangyou, et al. "Conductive line preparation on resin surfaces by laser micro-cladding conductive pastes." Applied Surface Science 233.1–4(2004):51-57.

[4] Yin, Jie, et al. "A finite element model of thermal evolution in laser micro sintering." International Journal of Advanced Manufacturing Technology 83.9-12(2016):1847-1859.

[4] E. Brandl, U. Heckenberger, V. Holzinger et al., “Additive manufactured AlSi10Mg samples using Selective Laser Melting (SLM): Microstructure, high cycle fatigue, and fracture behavior,” Materials & Design, 34, 159-169 (2012).
[5] L. Thijs, K. Kempen, J. P. Kruth et al.,“Fine-structured aluminium products with controllable texture by selective laser melting of pre-alloyed AlSi10Mg powder,” Acta Materialia, 61(5), 1809-1819 (2013).
[6] D. Buchbinder, W. Meiners, K. Wissenbach et al., “Selective laser melting of aluminum die-cast alloy-Correlations between process parameters, solidification conditions, and resulting mechanical properties,” Journal of Laser Applications, 27(S2), S29205 (2015).
[7] N. Read, W. Wang, K. Essa et al., “Selective laser melting of AlSi10Mg alloy: Process optimisation and mechanical properties development,” Materials & Design, 65, 417-424 (2015).
[8] K. G. Prashanth, S. Scudino, H. J. Klauss et al., “Microstructure and mechanical properties of Al-12Si produced by selective laser melting: Effect of heat treatment,” Materials Science and Engineering a-Structural Materials Properties Microstructure and Processing, 590, 153-160 (2014).
[9] X. P. Li, X. J. Wang, M. Saunders et al., “A selective laser melting and solution heat treatment refined Al-12Si alloy with a controllable ultrafine eutectic microstructure and 25% tensile ductility,” Acta Materialia, 95(0), 74-82 (2015).
[10] S. Siddique, M. Imran, E. Wycisk et al., “Influence of process-induced microstructure and imperfections on mechanical properties of AlSi12 processed by selective laser melting,” Journal of Materials Processing Technology, 221(0), 205-213 (2015).
[11] Zhang, Hu, et al. "Effect of Zirconium addition on crack, microstructure and mechanical behavior of selective laser melted Al-Cu-Mg alloy." Scripta Materialia 134(2017):6-10.
microstructure and mechanical properties,” Materials Science and Engineering: A, 656, 47-54 (2016).
[12] Kaufmann, N., et al. "Influence of Process Parameters on the Quality of Aluminium Alloy EN AW 7075 Using Selective Laser Melting (SLM)." Physics Procedia 83(2016):918-926.
[13] Sistiaga, Maria L. Montero, et al. "Changing the alloy composition of Al7075 for better processability by selective laser melting." Journal of Materials Processing Technology 238(2016):437-445.
[14] Wang, P., et al. "Selective laser melting of Al-Zn-Mg-Cu: Heat treatment, microstructure and mechanical properties." (2016).
[15] Hu, Zhiheng, et al. "Experimental investigation on selective laser melting of 17-4PH stainless steel." Optics & Laser Technology 87(2017):17-25.
[16] Yang, Jingjing, et al. "Cracking behavior and control of Rene 104 superalloy produced by direct laser fabrication." Journal of Materials Processing Technology 225(2015):229-239.