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Experimental investigation on densification behavior and surface roughness of AlSi10Mg powders produced by selective laser melting

Lin-zhi Wang *, Sen Wang, Jiao-jiao Wu

Chongqing Key Laboratory of Additive Manufacturing Technology and Systems, Chongqing Institute of Green and Intelligent Technology, Chinese Academy of Sciences, Chongqing 400714, PR China

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ABSTRACT

Effects of laser energy density (LED) on densities and surface roughness of AlSi10Mg samples processed by selective laser melting were studied. The densification behaviors of the SLM manufactured AlSi10Mg samples at different LEDs were characterized by a solid densitometer, an industrial X-ray and CT detection system. A field emission scanning electron microscope, an automatic optical measuring system, and a surface profiler were used for measurements of surface roughness. The results show that relatively high density can be obtained with the point distance of 80–105 μm and the exposure time of 140–160 μs. The LED has an important influence on the surface morphology of the forming part, too high LED may lead to balling effect, while too low LED tends to produce defects, such as porosity and microcrack, and then affect surface roughness and porosities of the parts finally.

1. Introduction

Aluminum alloys have excellent properties such as specific strength, stiffness, electrical and thermal conductivity. It has been the second widely used metal material in the world [1], whose application potential is only less than steels. With the fast development in aerospace, military engineering, energy, automobile and rail transportation industries, the applications of aluminum alloys with lightweight and high performance are increasing in those areas, whose aims to satisfy the requirements of functional, reliable, economic and lightweight equipment [2,3]. Currently, most of aluminum alloy parts are manufactured by casting, forging, extrusion and powder metallurgy. Those traditional processes have long production period and high cost. Moreover, parts with the complex shapes are difficult to be prepared by them, which restrict a further development and application of aluminum alloys [4]. Therefore, manufacturing aluminum alloy parts with complex shape in a more efficient and convenient way has been one of the hottest topics in the field of advanced manufacturing technology. Nowadays, Selective Laser Melting (SLM) is the most successful forming process for complex metal structures. Actually, this type of process has advantages of high degree of flexibility, complex shape designing and material saving [5–7]. Moreover, the part manufactured by SLM generally has much higher density and more excellent surface quality, which dismiss the shortcut existing in traditional aluminum alloy parts forming methods. Therefore, SLM technology has a promising market application prospect and high research value in aluminum alloy complex structure forming industry.

In fact, the heat source during SLM process has significant difference with traditional forming methods, which mainly performs in two aspects: (1) SLM forming equipment adopts a fiber laser device with high power density, and the laser spot diameter is always less than 0.1 mm, which melts solid powders in a rapid velocity [8]. (2) The SLM manufactured parts is formed by partition zones scanning, in addition, metal powders are molten point by point then consolidate together in layers. Local excessive accumulated heat in powder bed can dissipate through thermal conduction of substrate, therefore, the solidification rate of molten pools are extremely high [9,10]. As a result, those characteristics of SLM process mentioned above lead to the difference of density and surface roughness evolution mechanisms between SLM with traditional forming process. For aluminum alloys, due to the low melting point and high thermal conductivity, the SLM forming process has a larger heating and cooling rate. Therefore, it is necessary to carry out further study on the inner relationship between SLM process parameters and manufactured parts' density and surface roughness.

Gu et al. [11] researched densification behavior of TiC nanoparticle reinforced AlSi10Mg bulk-form nanocomposites prepared by SLM. They found that using an insufficient laser energy input of

* Corresponding author.
E-mail address: wlz@cigit.ac.cn (L.-z. Wang).

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250 J/m lowered the SLM densification due to the balling effect and the formation of residual pores. The highest densification level (>98% theoretical density) was achieved for SLM-processed parts processed at the aser energy input of 700 J/m. Dalgarno et al. [12] reported densification mechanism in selective laser sintering of Al-12Si powders, they pointed out that the degree of porosity and its orientation as well as the densification of the inter-agglomerates of Al-12Si parts made by direct SLS were controlled by the choice of processing parameters. Iuliano et al. [13] studied influence of process parameters on surface roughness of AlSi10Mg parts produced by direct metal laser sintering, it was found that scan speed had the greatest influence on the surface roughness. The best results were obtained with a scan speed of 900 mm/s, a laser power of 120 W and a hatching distance of 100 μm.

Above investigations reported single process parameter on density and surface morphologies of the SLM processed AlSi10Mg samples with continuous exposure scan pattern. Actually, there are two different laser scan pattern including point exposure scan and continuous exposure scan in SLM. However, comprehensive influence of process parameters on densification behavior and surface roughness of the SLM processed samples with point exposure scan are very limited. In this paper, laser energy density (LED) under point exposure scan pattern was introduced. Moreover, the influence of LEDs on density and surface roughness were investigated in details. The results provide theoretical basis for the aluminum alloy samples with high performance and high precision fabricated by SLM process.

2. Experimental procedure

2.1. Powder preparation

Hypoeutectic AlSi10Mg alloy has been used widely due to its good melt flowability, mechanical properties and corrosion resistance. Chemical composition of the AlSi10Mg powder used in this study is shown in Table 1. The AlSi10Mg powders are with spherical shape, and the spheroidization ratio of AlSi10Mg powders is almost 100% (as seen in Fig. 1(a)). In addition, Granulometric parameters of the AlSi10Mg powders were evaluated by a laser particle size analyzer (Fritsch Gmbh, Analysette22 MicroTec plus). The results show that the particle size of the AlSi10Mg powder is in the range of 5–50 μm (as seen in Fig. 1(b)).

2.2. SLM process

The SLM process is carried out by a Renishaw AM-250 powder-bed machine. The powders are melted by a diode pumped Nd: YAG laser with the maximum power of 400 W. The adjustable parameters are point distance and exposure time. As illustrated in Fig. 2(a), point distance is the distance between adjacent fusion points along laser scanning direction, and exposure time is the duration time of the laser remaining on each fusion point. In order to minimize part residual stress, a checkerboard scanning strategy was selected for all trials. For one specific powder layer, the checkerboard is scanning in a linear way, and the linear scanning direction rotates with 67° for the next processing powder layer, as shown in Fig. 2(b). Other parameters are set as constants and their effects on part's properties are not discussed here. Those parameters are listed in Table 2.

In the SLM experiments, an aluminum substrate was leveled and fixed on the building platform. The platform temperature was preheated and maintained at 150 °C in order to reduce residual stresses and distortion of components. The rectangular specimens with dimensions of 10 mm × 10 mm × 10 mm were built layer-by-layer until the whole shape completely formed.

The LED expressed by Eq. (1) describes the energy input per volume during SLM [14,15], and the LED is a combination of effects of the SLM process parameters.

$$LED = P/(vhd) \tag{1}$$

where P (W) denotes the laser power, v (mm/s) is the scanning velocity, h (mm) is the hatching space and d (mm) is the layer thickness. Further, the scanning velocity v is determined by:

$$v = P_{\mathrm{d}}/T_e \tag{2}$$

where P_{d} (μm) is the point distance and T_e (μs) is the exposure time.

Therefore, Eq. (1) can be drawn in another way as:

$$LED = PT_{\mathrm{e}}/(P_d hd) \tag{3}$$

Table 1
Chemical composition of AlSi10Mg.

Element	Cu	Mg	Fe	Si	Mn	Zn	Other	Al
Composition (wt%)	0.06	0.623	0.08	9.628	0.01	0.03	<0.2	Balance

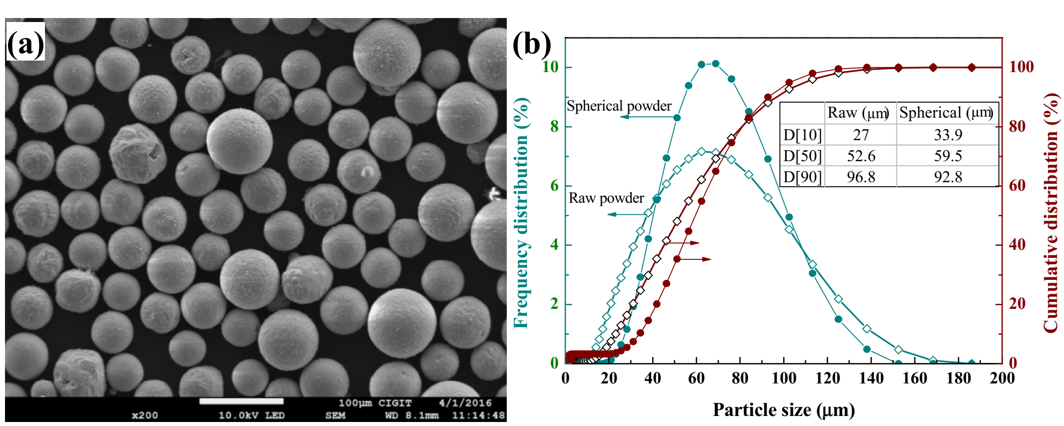

Fig. 1. Typical particle morphology and particle size distribution curve of the starting AlSi10Mg powder: (a) SEM image of AlSi10Mg powder and (b) particle size distribution curve.