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Process optimization and mechanical property evolution of AlSiMg0.75 by selective laser melting

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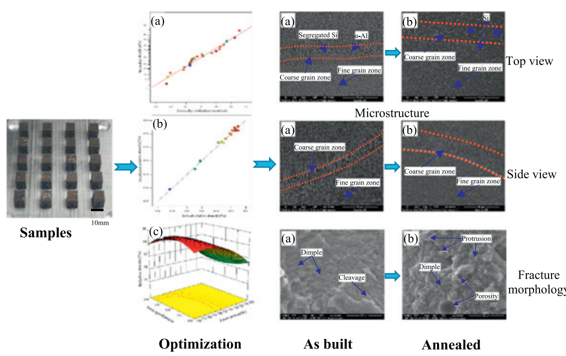
HIGHLIGHTS

- Central composite design of experiment approach is correlated for AlSiMg0.75 alloy manufactured by SLM.
- The relative density of AlSiMg0.75 alloy sample reaches to 99.0624%.
- Microstructure and microhardness of as-built and annealed AlSiMg0.75 alloy are both obviously different.
- As-built and annealed tensile properties of SLMed AlSi10Mg0.75 exceed the cast tensile properties.

GRAPHICAL ABSTRACT



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ABSTRACT

A central composite design of experiment has been carried out to investigate the effect of selective laser melting (SLM) process parameters on the relative density of AlSiMg0.75 alloy and obtain samples with relative density of 99.0624%. Square samples and flat tensile samples were manufactured with optimized process parameters to study the evolution of microstructure, microhardness and tensile property. The microstructure of as-built samples shows fine grains and coarse grains with Al-rich cellular structure and *Si*-segregated network structure in top view. However, a large number of dendrite grains with very small space are observed in side view. After heat treatment, the cellular and dendrite structure broke into particles of different sizes with microhardness reduction and Si phase appearance by XRD and DSC. The heat treated samples show lower tensile strength and yield strength with the reduction of residual stress and Si solubility, and the destruction of small structures. But the elongation is higher than the as-built ones. The fracture morphology of as-built samples shows cleavages with small and shallow dimples, which indicates a mixture of brittle and ductile fracture. The fracture morphology of heat treated samples shows big and deep dimples, which indicates a ductile fracture.

1. Introduction

Aluminum silicon alloy is characterized by its sound castability, good weldability and outstanding corrosion resistance. Owing to their excellent combination of low weight, high heat conductivity and good mechanical properties, they are widely used in aerospace, automotive and conventional manufacturing industries [1,2]. However, traditional manufacturing methods such as casting, forging, extrusion and rolling require costly and complex molds and heavy machinery, resulting in production cost and production cycle growth, inefficiency and a waste of labor. SLM is one kind of additive manufacturing technologies, which adopts high-power laser to scan metal powder layer by layer,

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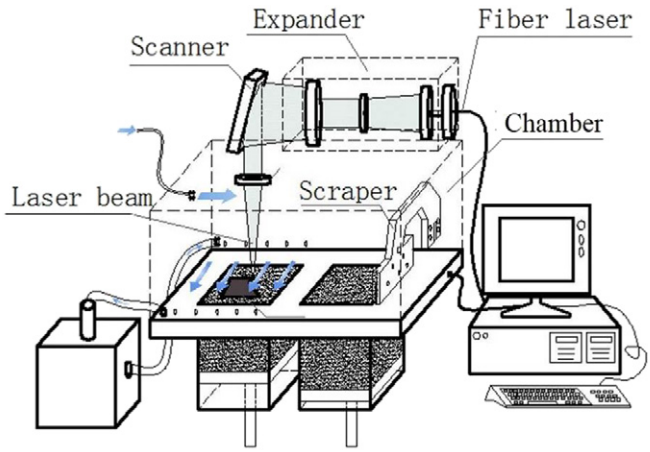

Fig. 1. Principle of SLM manufacturing.

Table 1
Chemical composition of the investigated AlSiMg0.75 alloy (Wt%).

Al	Si	Mg	Mn	Zn	Cu	Fe	Pb	Ni	Others
Bal.	12.02	0.77	0.035	0.022	0.0059	0.31	0.01	0.0058	0.07

so the parts with complex structure and high relative density can be achieved through metallurgical bonding between scanning tracks and layers. Compared with traditional manufacturing processes, SLM has the characteristics of high degree of freedom in manufacturing, low cost and high efficiency [3–5]. Due to a high cooling rate, very fine microstructure and excellent mechanical properties can be obtained [6,7].

The quality of aluminum alloy manufactured by SLM is affected by many factors such as material characteristics, equipment, laser power, scanning speed, hatching space and layer thickness. Generally, material characteristics, equipment and layer thickness (related to the size of the powder) are relatively fixed. So laser power, scanning speed and hatching space are the main process parameters for SLM parts. Response surface method is one of design of experiments which is very useful to study the effect of parameters on materials applications [8–10]. Noriko Read et al. [11] used response surface method to investigate the influence of SLM process parameters (laser power, scan speed, scan spacing and island) on the porosity development in AlSi10Mg alloy builds. Bacchewar et al. [12] used response surface method to study the significance of selective laser sintering process variables on surface roughness. As the high cooling rate in SLM results in a very special microstructure of aluminum alloy compared with conventional

Table 2
The range of matrix building parameters.

Factor	Units	Levels				
		−α	−1	0	1	+α
A:Laser power	W	99.55	120	150	180	200.45
B:Scanning speed	mm/s	397.73	500	650	800	902.27
C:Hatching space	μm	59.77	70	85	100	110.23

processes, some scholars have focused on the microstructure, microhardness and tensile strength of AlSi12 and AlSi10Mg alloy manufactured by SLM [13–17]. Since the standard manufacturing process of aluminum alloy manufactured by SLM has not yet been established, there are still many defects such as oxides, voids, cracks, residual stress and porosities [18,19]. In addition, although the hardness and strength of parts manufactured by SLM are higher than the ones of conventional parts, the elongation is very low, which cannot meet the requirements. So it is necessary to investigate the optimization of process parameters and heat treatment method for aluminum alloy parts to achieve more excellent comprehensive performance.

This paper aims to study the effect of SLM process parameters on manufacturing AlSiMg0.75 alloy with high relative density and the influence mechanism of heat treatment on microstructure, microhardness and tensile property of AlSiMg0.75 alloy. Statistical design of experiment (DOE) using response surface method was adopted to optimize the SLM process parameters to obtain the maximum relative density. Samples were manufactured by optimized process parameters. The DSC test of as-built samples and XRD test of as-built and annealed samples were carried out to study the phase changes. The microstructure, microhardness and tensile property of as-built and annealed samples were investigated to study the mechanical properties evolution.

2. Experimental methods

2.1. Equipment and material

Selective laser melting machine, manufacture by South China University of technology, equipped with a 200 W Nd-YAG laser with 70um diameter beam was used in the experiment. Fig. 1 shows the main components of the machine which is also equipped with precise scanning galvanometer and sealing manufacturing chamber. The AlSiMg0.75 powder, the composition of which is shown in Table 1, was manufactured through gas atomization method. Fig. 2 (a) shows a SEM micrograph of the powder. It is obvious that the powder particles are nearly spherical, but there are many small satellite particles attached to the big ones, which has bad effect on powder flowability. These small

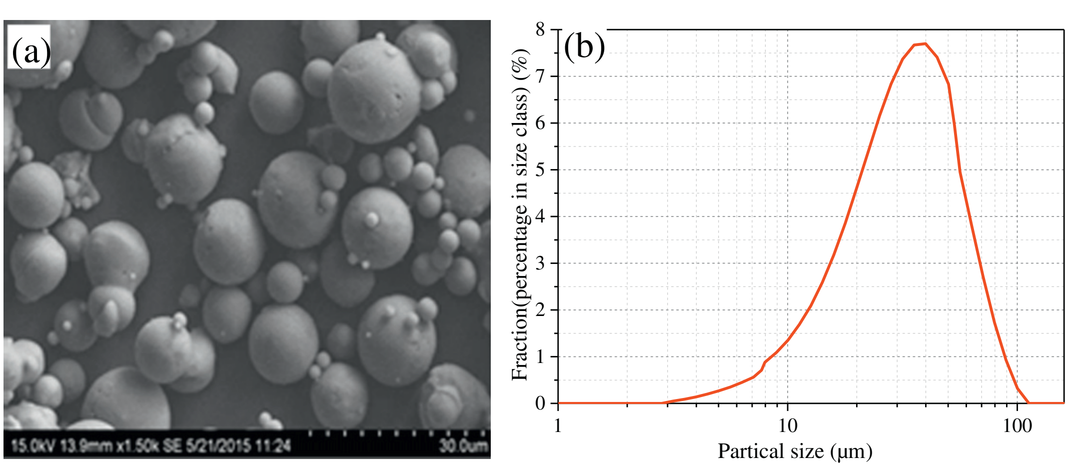

Fig. 2. Observation of aluminum alloy powder morphology by SEM (a) and particle size distribution (b).