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Featured Letter

Microstructure and mechanical properties of selective laser melted Mg-9 wt%Al powder mixture

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A B S T R A C T

Selective laser melting (SLM) of Mg-Al powder mixture is a promising method to additively manufacture Mg-Al alloy components without using pre-alloyed powder as feedstock. However, the microstructure and consequent tensile properties of SLMed Mg-9 wt%Al powder mixture have not been systematically investigated. In this work, spherical Mg and Al powder with a weight ratio of 91:9 were mixed using ball milling and the mixture was SLMed at different processing parameters. Mg-Al alloy was successfully fabricated and the highest relative density achieved was 95.7%. The results of scanning electron microscopy showed that the microstructure and volume of defects could be controlled by tuning the processing parameters. The highest ultimate tensile strength achieved was 274 MPa, which was comparable to the strength of SLMed pre-alloyed Mg-9 wt%Al as reported in literature. Based on this study, SLM of different Mg powder mixture can be investigated in future.

1. Introduction

Selective laser melting (SLM) is suitable for fabricating metallic products with complex geometries. SLM process of iron-based materials [1], Ti alloys [2], Ni alloys [3] and Al alloys [4] are intensively investigated. Mg alloys are promising materials for industrial and biomedical applications, because of their high specific strength, excellent biocompatibility and biodegradability [5]. SLM can enhance the mechanical properties [6] and corrosion resistance [7] of Mg alloys.

However, SLM of Mg and its alloys is still in its infancy. It has been reported that the processing parameters of SLM for Mg-based materials should be carefully chosen due to the materials' low melting and boiling points [6]. Variations of Mg alloy's chemical compositions have been reported by K. Wei et al. [8] due to element vaporization in SLM process. For this reason, the compositions of Mg alloy powder for SLM should be carefully adjusted and the processing parameters should be selected accordingly. Lack of specialized alloy powder hampers the development of SLM process of Mg alloys.

Powder mixture is an alternative to pre-alloyed powder. Compared with pre-alloyed powder, using powder mixture offers more flexibility in manufacturing/composition [9]. To enhance the mechanical properties of SLMed materials, pre-alloyed powder mixed with nano-particles has been used to manufacture metal composites [10]. B. Zhang et al. [11] report that SLMed Mg-9 wt% Al powder mixture had similar hardness compared with those commercially used Mg-9 wt%Al alloys. Therefore, SLM of Mg-Al powder mixture is a promising technique to manufacture Mg-9 wt%Al alloy. However, the highest relative density of the SLMed components was only 82% and the tensile properties were not evaluated.

In this work, the formability, microstructure and tensile properties of SLMed Mg-9 wt%Al powder were systematically investigated.

2. Experimental

Gas atomized Mg (99.81% in purity, d_{50} = 23.96 μm) and Al (99.99% in purity, d_{50} = 28.16 μm) powder were used. As shown in Fig. 1(a), morphologies of the powders are spherical. The powder mixture was blended in a vacuum ball mill machine for 1 h to ensure the powders were homogenously mixed.

Nd:YAG laser with 1064 nm wave length and 80 μm spot size was used to scan and melt the powder mixture. The process was protected by argon and the oxygen concentration in the building chamber was below 0.1%.

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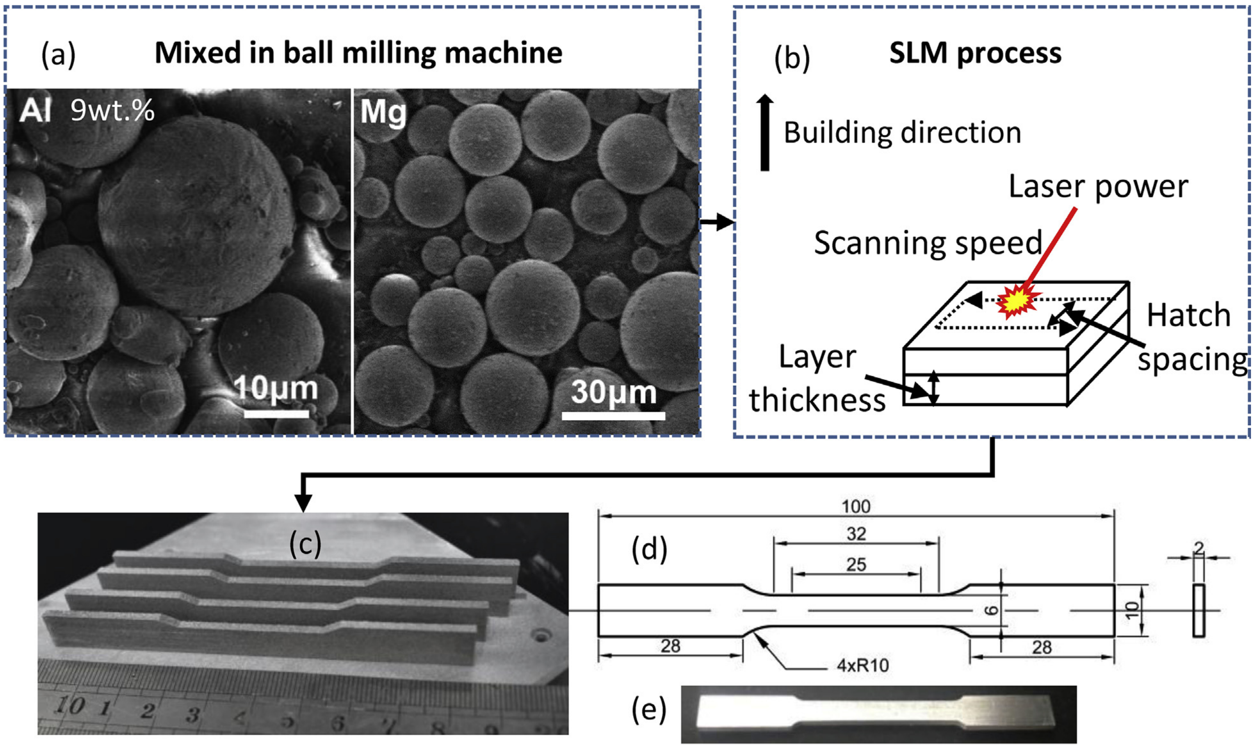

Fig. 1. (a) SEM images of the Al and Mg powder; (b) the schematic of SLM processing parameters; (c) SLMed components; (d) dimensions of tensile specimen; (e) SLMed tensile specimens (machined and polished).

According to several preliminary tests conducted by the authors, the optimized process parameters were set as: laser power (P) = 70 W, layer thickness (T) = 30 μm, hatch spacing (H) = 30 μm, scanning speed (S) = 500, 750, 1000, 1250 mm/s. Energy density can be calculated by

$$\text{Energy density} = \frac{P}{T \cdot S \cdot H}$$

Thus, energy densities correspond to the four different scanning speeds are 155.6, 103.7, 77.8, 62.6 J/mm^3, respectively. The scanning pattern used was meander and the scanning direction was rotated 90° when building every new layer.

Density of the SLMed components was examined using Archimedean method. As-rolled AZ91D material, which is a type of Mg-9 wt%Al alloy, was used as benchmark to calculate relative density. Tensile tests were conducted following the instructions of ASTM B557M-10 standard. Scanning electron microscope (SEM) was used to study the microstructure of the SLMed specimens, which were polished and etched before testing. X-ray diffraction (XRD) was used to examine the phase constituents of the powder mixture and the SLMed components.

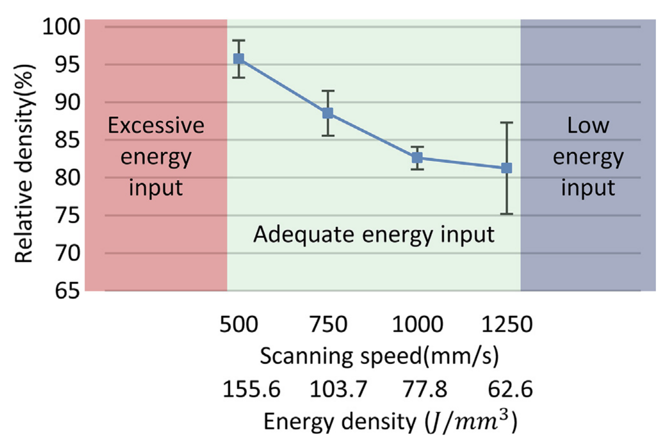

Fig. 2. Relative density of the SLMed components manufactured at different energy inputs.

3. Results and discussion

3.1. Relative density

As shown in Fig. 2, the relative density reaches the highest value (95.7%) when scanning speed is 500 mm/s (energy density = 155.6 J/mm^3). It is significantly higher than 82%, as reported by B. Zhang et al. [11]. This is mainly because spherical powder used in the experiments had better flow-ability and laser absorbability than irregular powder. Energy density higher than 155.6 J/mm^3 caused severe evaporation of the material. Energy density lower than 62.6 J/mm^3 was insufficient since it leaded to high porosity, which is detrimental to the mechanical strength of the SLMed components.

3.2. Microstructure

Fig. 3 shows XRD patterns of the powder mixture and the SLMed components manufactured at different scanning speed. The results demonstrate Mg-Al alloy, which consists of α-Mg solid solution and β-Al12Mg17 compound, was successfully produced from the powder mixture by SLM process. There are no obvious peaks of Mg or Al oxides in the graphs.

Al dissolved in Mg while the powder was melted, forming a Mg-Al liquid phase. As the melted material solidified, the liquid phase were transformed to α-Mg solid solution and β-Al12Mg17 precipitates.