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Comparisons on microstructure, mechanical and corrosion resistant property of S136 mold steel processed by selective laser melting from two pre-alloy powders with trace element differences

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ABSTRACT

Selective laser melting (SLM) method has a great potential for fabricating injection mold with complex structure. In this study, two S136 mold steel pre-alloy powders with trace element difference were fabricated by SLM, and then comparison of samples on microstructure, mechanical and corrosion resistant property was investigated. Results showed that the sample fabricated with a higher Si+Mn content exhibited the lower mechanical properties, such as micro-hardness of 48.73 HRC, ultimate tensile strength of 1186.7 MPa and elongation of 10.6% due to a few of pores observed on the cross surface. For the SLM sample produced by another powder with a lower Si+Mn content, it showed equiaxed grains and cellular dendrite grains coexisted and exhibited the superior mechanical properties (50.31 HRC, 1467.9 MPa and 11.1%) combined with well corrosion resistance. Then the injection mold insert with conformal cooling channel was successfully processed by this powder. The cooling time was reduced by 30% during the injection cycle. Therefore, it can be seen that trace element differences have an important effect on the SLM S136 mold steel. The results suggest that it is essential for successful fabricating components with a suitable composition of alloy during SLM process.

1. Introduction

Mold steels are widely used in injection molding and sheet metal forming industries. Many grades of mold steel have been studied and developed in recent years. Such as NAK80 mould steel, developed by Daido Steel, Japan, is a pre-hardened steel used for making plastic moulds with better quality and low costs. H13 steel is a hot work steel used for making molds for cutting, forming, and shaping materials because of its sufficient elastic strength, wear resistance, and high temperature stability [1]. With the geometrical shapes of commercial products become increasingly complex, the requirement for fabricating mold steel with complex structure has arose [2]. For example, injection molding steel with complex conformal cooling channel can accurately control the temperature of the molding cavity throughout the processes cycle, hence leading to shortening cycle times and producing parts with lower residual stresses [3]. However, current fabricating methods have severe limitations on the complex geometries.

Selective laser melting (SLM) is one of the additive manufacturing technologies. It can be used for fabricating near-fully dense and complex metal parts directly from computer-aided design (CAD) models [4–6], hence showing a great potential for fabricating mold steel with complex conformal cooling channel and geometries. Recently, some preliminary investigations have been carried out to study the process and mechanical property of the mold steels fabricated by SLM. Childs et al. [7] found there was a scan speed range in which the layer mass increased/fluctuated with increasing scanning speed for H13 steel processed by SLM. Zhao et al. [8] explored the evolution mechanism of carbon during selective laser melting AISI 420. And it was found 21% carbon was lost and the decarburization occurred. Almangour et al. [1] investigated the effect of TiC addition on the mechanical properties of H13 steel and found the TiC/H13 steel nanocomposite parts exhibited higher hardness and elastic modulus, lower friction and a lower wear rate.

Besides, it has been confirmed that the element or composition difference of alloys has an important role in controlling the

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microstructures and texture during the SLM process. Vrancken et al. [9] found that the Ti6Al4V with higher Mo content (10 wt%) could obtain the novel microstructure and solidification mechanism. And the tensile properties were equal to or better than conventional β titanium alloys. Tomus et al. [10] studied the effects of minor elements of Hastelloy X on the crack susceptibility and found that micro-segregation of these elements towards the grain boundaries was resulting in brittle phases and increasing the chance of micro-cracking. Also Harrison et al. [11] pointed out that certain alloys suffer from thermally induced micro-cracking during SLM, which cannot be eliminated by process optimization but can reduce by increasing its Thermal Shock Resistance (TSR) elements.

However, to the best of the authors' knowledge, few previous researches studied the effect of composition of the SLM mold steel alloy on the microstructure and mechanical property. Therefore, two S136 pre-alloy powders with slight composition deviation were chosen to investigate the influence of composition deviation on the microstructure, mechanical property and corrosion resistance processed by SLM.

2. Experimental details

2.1. Materials

Two S136 mold steel bars with trace element difference (named #1 and #2, respectively) were produced by casting. Then the bars were used for producing powders by gas atomization (Changsha Hualiu Metallurgy Powder Co., Ltd., China) in this study. Fig. 1 showed the morphology and the powder size distribution of these S136 mold steel powders. The powder particles were generally spherical with an average size of 25 μm, which was proper for the SLM process.

The real chemical composition of the powders were listed in Table 1, which were conducted by direct-reading inductively coupled plasma emission spectrometer (Optima 4300DV, Perkin Elmer Ltd., USA). Table 1 detailed the composition difference of the #1 and the #2 powders.

2.2. Experimental procedures

The SLM machine (SLM125 Solutions, Germany) equipped with a 400 W laser (IPG Laser GmbH, Germany) and an inert argon gas protection system was used for fabricating the S136 mold steel samples as shown in Fig. 2a. And Fig. 2b shown the top view and side view illustration of SLM sample. The SLM process was conducted in a high purity argon atmosphere (99.9%) to avoid the oxidation. The processing parameters were optimized as follow: the laser power of 250 W, scanning speed of 650 mm/s, hatch space of 0.06 mm and the layer thickness of 0.02 mm.

2.3. Characterization

The density of sample was measured by the Archimedes method. The morphology and microstructure of the sample was analyzed by SEM (JSM-7600F, JEOL, Japan). The element variation was investigated by the energy dispersive X-ray spectrometer (EDS) equipped on the SEM. The phase was identified by XRD analysis (Philips Co. Ltd., X' Pert diffractometer with Cu Kα radiation at 40 kV and 50 mA). The cross section was prepared by standard cutting and polishing technique, and then etching for 10–15 s with a solvent (10 g $FeCl_3$, 120 mL H_2O and 30 mL HCl). Polished sample was prepared for Rockwell hardness testing (Wilson Hardness 600MRD, USA) under a maximum load of 1 kg and a dwell time of 15 s at room temperature. The tensile strength of the specimens

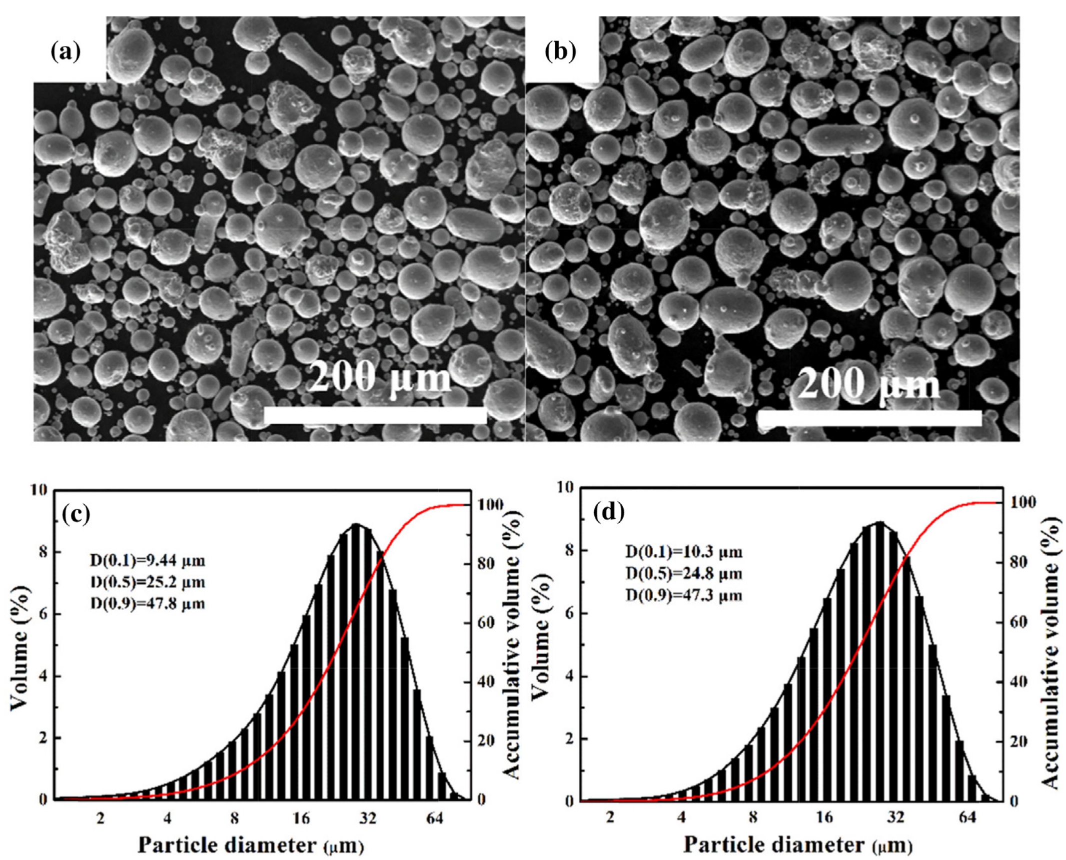

Fig. 1. SEM of S136 powders (a) #1 (b) #2 and particle size distribution of the powders (c) #1 (d) #2.