Rapid Manufacturing Metallic Parts via Selective Laser Melting

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Abstract
316L stainless steel parts were manufactured via selective laser melting in this work. The surface morphology, microstructure, density and mechanical property were characterized. It is found that the surface contains a little amount of oxide and splash with balling effect. Microstructure in low magnification shows features of scan molten tracks and molten pools; microstructure in high magnification depicts very fine crystal under rapid cooling. The tensile strength of as-received samples is 652.12 MPa, with a density of 95.6%. Therefore the gas atomized 316L stainless steel powders could be used in manufacturing high quality parts with complex shapes via selective laser melting method.
Keywords Selective laser melting, metallic parts, 316L stainless steel, powder

1 Introduction

Selective laser melting (SLM) is a newly developed rapid manufacturing technology, which can directly manufacturing intricate metal parts according to a three dimensional model from metal powders[1-4]. This forming technique is based on means of adding layers to build net shape components. Each layer represents a slice geometry graph of the objective part in two-dimensional pattern. Owing to its unlimited flexibility of geometry and complexity, SLM is capable of manufacturing short run components which are not easily made through other forming method. Moreover, metal parts made by SLM need no or very little post-processing procedure, and it is differ from selective laser sintering (SLS). During SLM process, metallic powders are fully melted because of a higher laser energy input. While in SLS process, the forming mechanism is melting high polymer powder to binder un-melted metal powder. Thus SLS needs very trivial procedures such as post treatment to degrease to remove the binder. So it is urgent to develop and optimize SLM technique with an aim to improve its practicability and universality in advanced manufacturing field.

At present, SLM technology is faced with many problems such low density, balling phenomenon, delaminating, warp and crack etc. That is due to the complex heat transfer mode under rapid moving Gauss heat source, inducing acute temperature variation[5-6]. Metal powders are melted in an extremely short time coupled with multi-lines and multi-layers process, resulting in a very complex physicochemical process and multi modes heat and mass transfer. Under this circumstance, the densification is especially important for creating high quality parts. In addition, the as prepared microstructure is particular comparing with other microstructure obtained from conventional forming method. Therefore, investigation into a series of special phenomenon during SLM is essential. In this paper, the densification, microstructure, balling effect, mechanical property of 316L stainless steel part was presented and the corresponding mechanisms were also addressed.

2 Experimental Procedures

2.1 Powder Materials

316L stainless steel powders (99% purity) were used in this experiment. These powders were prepared through water atomization in institute of powder metallurgy, Central South University (CSU). The morphology of the starting powder was examined by a Quanta 200 scanning electron microscope (SEM). It can be seen that these powders show sphere shape and bimodal-size feature, which can induce a high loose density and it is favorable for SLM experiment.

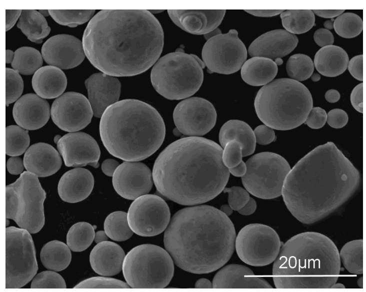


Fig.1 SEM figure showing morphology of 316L stainless steel powders

2.2 SLM Forming

The forming process was carried on in the HRPM-*II*SLM system which was developed by Huazhong Univ. of Sci.&Tech. (HUST). The shaping space of the equipment was 250mm(L)×250mm(W)×200mm(H). This SLM equipment contained a 100W continuous wave fiber laser. The building chamber of this system could also be vacuumed and protected by inert gas. Forming process of SLM was followed the listed procedures.

(i) build 3D-CAD model and transfer it into STL file. Slice this 3D-CAD model into horizontal layers according layer thickness and input it into SLM system

(ii) a quality of powders is dropped, then a roller spread a powder layer

(iii)high energy laser scan the powder bed, thus the powders in scanned zone are completely melted

(iv) the working platform descend a layer thickness

(v) repeat procedure (b)-(d) until an integrated part is formed

Scan speed of 50∼100mm/s, laser power of 90∼100W, scan interval of 0.05∼0.2mm and layer thickness of 0.02∼0.1mm were selected for SLM process. Using above procedures and processing parameters, samples of SLM-parts can be made as shown in Fig.2.

(a) (b)

Fig.2 Samples of as fabricated SLM parts

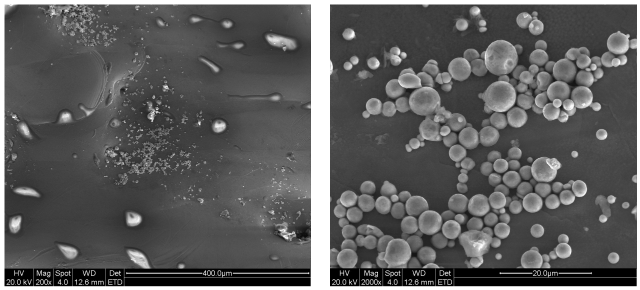
2.3 Characterization

At laser, densities of SLM parts were measured through Archimedes laser. Surface morphologies and microstructure of as-received samples were analyzed by a Quanta 200 SEM. The element composition of the laser processed material was measured by energy dispersive X-ray spectrometer analysis.

3 Experimental Procedures

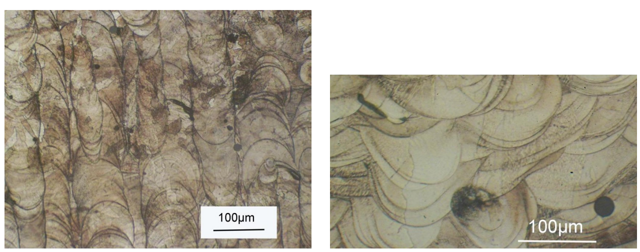
3.1 Surface Morphology

Surface characteristic could represent melting and solidification feature of SLM process. Fig.3 shows the surface morphologies. From the low magnification of Fig.3a, it can be seen that the surface is relatively smooth in addition to some white flakes and splash. EDX analysis resulted that the white flakes on the surface were oxygen rich, which is formed because of oxidation. It should be noted that the oxidation is disadvantageous for SLM technique, due to a worsened wetting ability caused by oxide. In next layer forming process, the melted liquid could not wet the previous layer easily. Therefore, it should be cautious to control oxygen content in atmosphere to prevent oxidation. Moreover, it also should control oxygen contents in powder materials. Fig.3b is the high magnification of splash form Fig.3a, showing the detailed characteristic of splash. It exhibits spherical feature, with a large number of spheres on the top surface. The formation mechanism of balling effect during solidification process can be explained as follow. In liquid metal solidifying process, the surface energy tends to reach a lower value which is according to the lowest energy principle. Thus under surface tension action, the many spheres are generated.



(a) (b)

Fig.3 SEM figure showing top surface morphologies of as prepared part

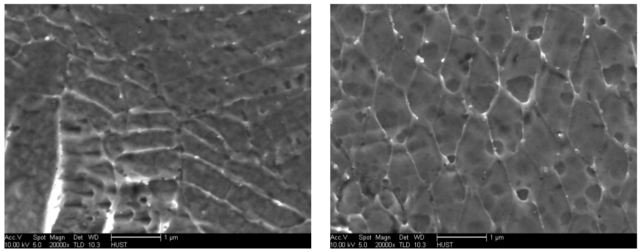


(a) (b)

Fig.4 Metallograph showing low magnification of microstructure. a: top view; b: side view

3.2 Microstructure

SLM-produced microstructure is very different from microstructure obtained by conventional forming method. Hence investigation on its microstructure is requisite. Fig.4 shows the metallograph of top view and side view respectively, overall it can be seen that the microstructure in low magnification is dense with few pores. It is widely accepted that pores in a metal part are detrimental to mechanical property, so a high density is a significant index of a metal part. In this work the final density of 316L stainless is 95.6%, which is measured by displacement method. Consequently this dense structure facilitates mechanical property. Fig.4a describes the microstructure from top view. It can be seen that scan tracks are overlapped, and formed into a dense layer. Fig.4b shows the microstructure from side view. It indicates that molten pools are accumulated tightly with a small amount of pores. Fig.5 illustrates the microstructure in high magnifica-



(a) (b)

Fig.5 SEM figures showing microstructure in high magnification of SLM-produced material

tion of SLM-produced material. It is obvious that the grains are very fine and the grains grow along multiple directions. The extremely fine size is caused by the significantly rapid cooling rate during solidification process. A rapid solidification could inhibit grain growth, accordingly forming a large number of fine grains. The grains during molten pool solidification tend to grow along the easy growth direction. For cubic crystal, the growth directions are $< 110 >$. When one of the easy growth directions coincides with the heat flow direction, growth conditions are optimum. For this reason, among the randomly oriented grains, those grains have one of their $< 100 >$ crystallographic axis most aligned with the heat flow direction will be favored. However, SLM is a multi-line based technology in every CAD slice layer, the moving heat resource controlled by a complex scan path can easily induce a very complicated heat diffusion process, thereby a varied heat transfer direction. This reason leads to a variable growth direction in order to accommodate heat flow direction. Thus the as-received microstructures are formed. Here, it should be pointed out that the SLM produced parts contain fine microstructure, which is in favor of mechanical property.

3.3 Tensile Strength Evaluation

Mechanical property is an important factor which ultimately determines its practical application. Thus the tensile strength experiment was conducted with an eye to evaluate its mechanical property. A tensile test specimen was made by wire-electrode cutting from bulk SLM fabricated samples. Fig.6 expresses the stress-strain curves of extension test of SLM-prepared 316L stainless steel materials. By calculation from above data, the tensile strength value of 652.12 MPa is obtained. To an extent, this mechanical property is equivalent to forgeable piece. Therefore, this SLM-produced parts can be used as many practical requirement in metal components.

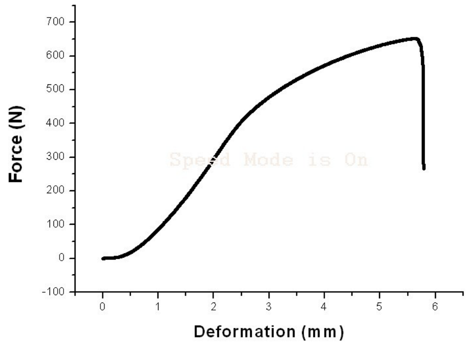


Fig.6 Stress-strain curves from extension test

4 Conclusions

Based on the investigation on selective laser melting 316L stainless steel powders, the following conclusion can be drawn. The gas atomized 316L stainless steel powders with spherical shape could be used as SLM material for rapid manufacturing metallic parts. The corresponding properties and characteristic for evaluation SLM-produced material are addressed. The surface morphology shows multi-lined feature, with a little amount of oxide and splash with balling effect. Moreover, the microstructure in low magnification is composted of scan molten tracks and molten pools, which reflect the accumulative characteristic of rapid prototype technique. The microstructure in high magnification indicates the intrinsic nature of rapid cooling rate, resulting in extraordinary fine crystal. Finally, the density of 95.6% is measured by drainage, possessing of tensile strength of 652.12 MPa. Overall, SLM technology in manufacturing 316L stainless steel parts shows its excellent feature in both flexible formability and high mechanical property, which can meet demand for practical applications.

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