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Effect of linear energy density on pores of 316L stainless steel by selective laser melting

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Abstract: The defects of forming parts with different process parameters (laser power, scanning speed and scanning distance) were studied by microscope, including air bubble, pore, micro-crack and macro-crack. The micro-structure and composition of the defects were studied by means of SEM and EDS. The results showed that the pore mainly included circular air pore, irregular process pore and oxide inclusion. Linear energy density(E=P/v)was introduced as synthetic parameter. The pore decreased gradually with increasing linear energy density .

1. Introduction

Selective Laser Melting (SLM) is a mature technology in metal 3D printing, which has great advantages in strength, precision and compactness, and has become one of the most promising technologies in additive manufacture(AM). Selective laser melting adopts powder-laying mechanism. The metal powder is melted layer-by-layer by high-energy laser. After absorbing the laser energy, the temperature of the metal powder rises sharply to the melting point, and the temperature drops sharply with the laser moving to solidify. SLM is suitable for micro-structure parts, small size parts and high precision parts, with density close to 100%, and dimensional accuracy up to 20-50um, surface roughness up to 20-30um [1-4]. SLM has developed rapidly in the fields of machinery, medical, aerospace and military.

The selective laser melt forming process is a complex dynamic non-equilibrium process. There are phenomena such as heat transfer, melting, phase transition, gasification and mass transfer. The high-energy laser moves at a speed of 2000m/s or higher during the forming process.When the laser spot leaves, The temperature of original tiny melting pool will drop sharply,10^3 K/s, the melting and solidification process of the metal powder will be less than a few milliseconds, which is easy to produce defects such as spheroidization, pores, bubbles and cracks, etc. So far, no defect-free SLM metal samples have been reported[5-9] .

316L stainless steel belongs to austenitic stainless steel. The thermal conductivity is about half of that of low carbon steel, but the linear expansion coefficient is about 50% of low carbon steel, and the alloying degree is higher,up to 30%. In this paper, 316L stainless steel is used as raw material.After preparing the samples with different process parameters, the causes of various defects were analyzed.The process parameters of 316L stainless steel with no crack, no bubble and a few pores and density of 99.7% were obtained.

2. Experiments

2.1. Raw material and properties
Gas atomized 316L stainless steel powder provided by Zhong-wu material Co., Ltd., China was used in the experiments. The chemical composition was shown in Table 1, and the average particle size was 30 um.

Table1. Chemical composition of 316L stainless steel used in SLM forming

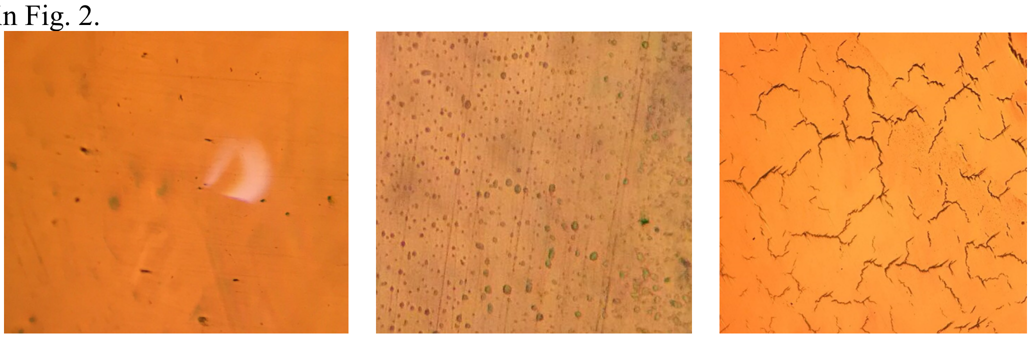
chemical composition/%								
Material	C	Si	Mn	P	S	Ni	Cr	Mo
316L	≤0.03	≤1.00	≤2.00	≤0.035	≤0.03	10.0-14.0	16.0-18.0	2.0-3.0

2.2. 1.2 Experimental process parameters
In this paper, the linerar energy density is selected as synthetic process parameter, which mainly reflects the comprehensive parameters of the laser in the process parameters. Linear energy density is E =P/v, where P is the laser power and V is the laser scanning speed, the input energy per unit length.

In this paper, 316L stainless steel powder is used as raw material and oxygen content in forming cavity is controlled below 100ppm. The sample size was 10×10×10 mm with different process parameters, and the forming samples were shown in figure 1.

Figure.1 The experimental test sample

3. Analysis of experimental results
Due to the material properties, molding atmosphere, process parameters and equipment conditions, a series of defects are produced in SEM process. The main defects are pores, bubbles and cracks, as shown in Fig. 2.



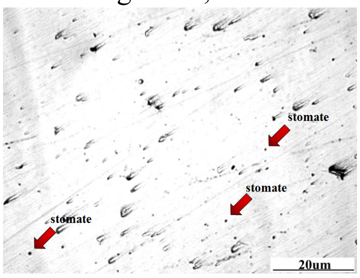
（a）pore （b）bubble （c）crack

Figure.2 SLM defects

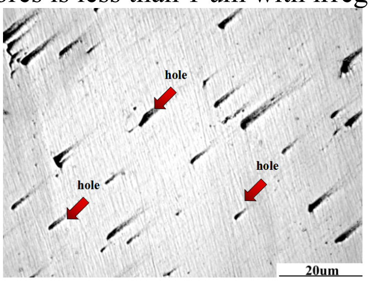
Table2 .Process parameters of SLM Experiment

number	Laser power w	Laser speed mm/s	liner energy density J/m
1	200	1400	142.8
2	200	1300	153.8
3	200	1100	181.8
4	200	800	250

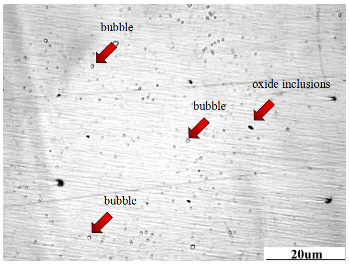
The selected laser melting process parameters are shown in Table 2. By means of a metallographic microscope, the defects of the samples are observed by magnifying 100 times. As shown in Fig. 3 below, when the liner energy density is less than 250 J / m, the main defects are pores, and the size of the pores is not uniform. In general, the diameter of pores is less than 1 um with irregular distribution.



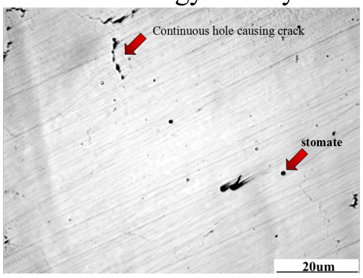
（a）liner energy density142.8J/m



（b）liner energy density153.8J/m



（c）liner energy density181.8J/m



（d）liner energy density250J/m

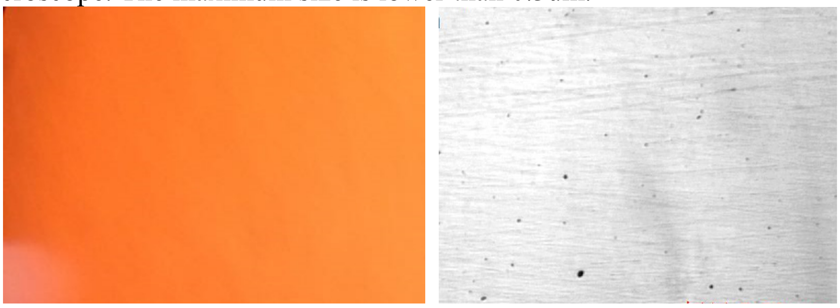
Figure.3 pore defects of microscope (100X)

Figure 3 (a) shows the pore diagram at 142.8 J/m. Due to the low linerar energy density, part of the metal powder is not melted. After polishing and corrosion, most of the pores appear as voids, tadpole-shape, and there are a few stomates. Figure 3 (b) shows the distribution of pores at 153.8 J/m, the number of pores decreases, and there are four different mixed types of pores. The distribution of pores at 181.8 J/m of linerar energy density is shown in figure 3 (c). The pores are mainly micro-pores with a size lower than 0.15um and oxide inclusions. Figure 3 (d) shows pore diagram at 250/m, which shows that the pores decreased obviously with a few stomates, but cracks begin to appear. As shown in figure 3, with the increase of energy density, the pores gradually decreases, and the type of pore evolves into a mixed type. Latter, the pores are mainly stomates formed after the gas escaping from the liquid metal gasification, and cracks are gradually produced.

4. Optimization experiment

The lower liner energy density causes pores and the high liner energy density causes the micro crack or even cracking. Therefore, it is necessary to adjust the process parameters to obtain the optimal product performance. In this subject, the better process parameters of 316L stainless steel are laser power 190-210KW, laser speed 800-1000mm/s, scanning distance 0.9-0.11mm, liner energy density is about 200J/m.The samples are no crack, no bubbles and a small amount of pores with density up to

99.7%. As shown in Figure4 (a), the digital photograph with the process parameters is smooth and smooth. There is no obvious defects. A small amount of pores appeared under 100 times of the metallographic microscope. The maximum size is lower than 0.3um.



（a）Digital photograph （b）Low fold defect map（100x）

Figure.4 Low-time defect

5. Conclusions

The defects of selective laser melting preparing 316L stainless steel include pores, bubbles and cracks, mainly due to the laser process, temperature gradient and the physical of the metal powder itself. The parameter of linear energy density in introduced a comprehensive index to analyzed relationship between process parameters and defects.

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