The Relation of the Uniformity of Composition and the Mainly Mechanical Properties of AlSi10Mg by Microanalysis in SLM

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Abstract: In order to search the relationship of microstructure and mechanical properties of metal 3D printing, the comprehensive properties of metal 3D printing through the comparison of 3D printing aluminum alloy and cast aluminum alloy were studied in the following three aspects: microstructure, hardness and tribological property. The experimental results show that the grain structure of 3D printing aluminum alloy was finer than that of cast aluminum alloy, and the distribution of various alloy elements was more uniform. which caused the hardness of 3D printed aluminum alloy was slightly higher than that of cast aluminum alloy, and the friction coefficient of 3D printing aluminum alloy was smoother than that of cast aluminum alloy. And the friction coefficient was smaller than casting in friction tests. Therefore, the result is that 3D printing aluminum alloy has the good mechanical properties due to the grain finer and uniform composition.

1. Introduction

3D printing, also known as additive manufacturing (AM) or rapid prototyping (RP), has become an emerging processing technology over the past 20 years because with it, the part molding, especially those difficult to machine, can be realized, a higher processing accuracy can be obtained, and the material utilization can be improved [1]. Recently, 3D printing technology for metallic materials has become the priority in the manufacturing industry worldwide [2-3]. In many countries such as the United States, Germany, Sweden and China etc, this technology has been applied in the aerospace manufacturing, and biomedical implants etc. [4-8].

Light in weight, high in specific strength and good in thermal conductivity, aluminum alloy was widely used in the aviation industry [9]. For the complex parts which were small in quantity but difficult to machine, 3D printing technology has the advantages over the traditional casting one of low cost, little pollution and high efficiency. What’s more, the 3D printing aluminum alloy was superior to the cast aluminum alloy in the tensile strength, elongation and hardness etc. [10]. However, few studies have been done on other mechanical properties, such as tribological properties, especially the grain structure and its relationship with the properties of 3D printing aluminum alloy. Therefore, this paper researched the mainly mechanical properties thought comparing with the 3D printing aluminum alloy and the casting one to prove the relationship between microstructure and mechanical properties of metal 3D printing.
2. Experiment process and method
The composition of cast aluminum alloy (Chinese Grade: ZL104 T6, ISO Grade: AlSi10Mg, sample named CAA) and 3D printing aluminum alloy (AlSi10Mg powders, sample named PAA) was similar to do the believable comparative test. They were randomly sampled in order to make the comparison results universally applicable in industrial applications. The chemical composition of this material was displayed in Table 1. CAA specimen adopts the pouring process to cast into according to the standard [10]. PAA specimen were directly printed using high purity AlSi10Mg powder (from the German EOS, particle size of about 250 mesh). 3D printing equipment was the German EOS M290 in the test. The process was that powder was filled and scraped through the scraper. Process parameters: laser sintering power 200W, scanning speed was about 1m/s, the powder layer was 0.06 mm. All samples were cylinder, the diameter was 30mm, the thickness was 10mm.

Table.1 Comparison table of main chemical components of AlSi10Mg (%)

| Sample  | Si    | Mg    | Mn    | Fe    | Cu    | Zn    | Ti+Zr | Sn  | Pb  | Al   |
|---------|-------|-------|-------|-------|-------|-------|-------|-----|-----|------|
| AlSi10Mg| 9.0-11.0 | 0.17-0.3 | 0.2-0.5 | ≤0.60 | ≤0.1 | ≤0.2 | ≤0.15 | ≤0.01 | ≤0.01 | other |

Firstly, the microstructure of two kinds of process samples CAA and PAA were analyzed by KH-1300 HIROX 3D video microscope. Secondly, the GSM-6390A scanning electron microscope was used to analyze these samples, including secondary electrons, backscattering, energy spectrum analysis (EDS), and so on. Then, the hardness of specimens was measured by HXD-2000TM/LCD micro hardness tester (the load 300g, and the holding time of 15s). Finally, the friction wear properties of specimens were tested by wear testing machine HT-1000. This pair grinding ball material was GCr15 (quenching, with the diameter of 6 mm, HRC>62). Test parameters: friction radius R=3 mm, speed of 560 rpm, 150g normal load, friction test time was 40min. The dry friction characteristics were tested at room temperature. The wearing loss of two kinds of sample were measured using EP120A 1/10000 scale weighing.

3. Test results of microstructure and alloy component
3.1. The surface topography
In Fig.1, the PAA and CAA specimens were observed under scanning electron microscope with the same magnification. The microstructure of PAA was more detailed than CAA. The large circular shape region was produced when the powder particles fall off in the process of the sample polishing. The microstructure of the PAA was refined than the CAA.
Fig. 1 (a) was the back scattered photo of CAA. The photo was composed of the white area and contrast gray area, according to EDS analysis in figure 1 (c). The white contrast area was rich-Si phase, and its composition was Si: 93.5%, Al: 6.4%, other: 0.1%. The relative gray contrast area was rich-Al phase. In the EDS analysis of CAA, main components in area 011 were Al: 88.06%, Si: 10.86%, Mg: 0.7%, Mn: 0.06%, Fe: 0.02%, and others: 0.3% in Fig. 1 (d). Fig. 1 (b) was the back scattering image of PAA. The sample surface was provided with the pits due to individual grains fall off, so the contrast difference was not obvious. The small bright spot was dispersed in the gray contrast matrix. The only small area 002 was done EDS analysis because of these grains was too small in Fig. 1 (e). The main components include Al: 77.53%, Si: 21.65%, and others: 0.82%. Fig. 1 (f), the components in area 012 were Al: 88.87%, Si: 10.1%, Mg: 0.75%, Fe: 0.07%, Zr: 0.06%, others: 0.15%. Therefore, in any area within the two samples, components of the PAA and CAA were very close. Further analysis was obtained, CAA has obvious grain aggregation due to the influence of different temperature when casting cooling. PAA not observed grain aggregation area, for the grain microstructure was refined due to rapid heating and cooling and it couldn’t spread during laser sintering process.

3.2. EDS elemental analysis

Fig. 2 (a) and (b) were Al element distribution diagram of two kinds of specimens. The results show that the Al element distribution was relatively uneven in CAA sample. There were black poor-Al regions (see black spots in Figure 2 (a)), this the region could be compared with the white rich-Si in Figure 1 (a). However, the Al element distribution of PAA sample was very uniform, and there was no obvious poor-Al region. Fig. 3 (a) and (b) were Si element distribution diagram of two kinds of specimens. The distribution of silicon in CAA sample was not uniform, rich-Si region was light (see...
light spots in Fig. 3 (a)). The rich-Si region could be compared with the white rich-Si phase in Fig. 1 (a) and the black spot in Figure 2 (a). But the Si element distribution of PAA was relatively uniform, and there was no obvious rich-Si area. Comprehensive back scattering and energy spectrum analysis, the results show that the elements of PAA process were relatively uniform and the organization was relatively fine.

4. The mechanical properties analysis

4.1. Surface hardness test
Micro hardness test was carried out on the CAA and PAA specimens. The results of the hardness of the two kinds of sample were shown in figure 4. The hardness of CAA was maximum value was 107.7HV, the minimum value was 99.8HV and so the average value was 102.9HV. The maximum hardness value was 131.0HV, the minimum was 128.8HV and the average was 129.9 HV on PAA. The hardness of PAA was slightly higher than CAA. The main cause was that the Si element in the PAA was more detailed and uniform than the CAA. In addition, from the smoothness of the curve point of view, 3D printing aluminum alloy hardness was more uniform and good consistency, which reflects the effect of the element distribution on the hardness.
4.2. Tribological properties

In order to further analyze the tribological properties of the specimens, dry friction and wear test was carried out. Line a was the friction factor (μ1) curve of CAA in Figure 5. By statistics, the average friction factor was 0.588 in the experimental process of 40min. Line b was the friction factor (μ2) curve of PAA in Figure 5. By statistics, the average friction factor was 0.509 in the same processing time.

From the graph 5 line a, according to the above spectrum analysis. The local distribution of the individual elements (such as Si-rich phase) in CAA was not uneven. Therefore, the local hardness difference was very big, and the friction coefficient curve has obvious fluctuation, and μ1 increase gradually by the change of furrow action. Analysis of friction coefficient curve of PAA from line b Fig.5, in the early stage of friction (0~3min), it was mainly that grinding ball and grinded surface was point contact and surface hardening by the material surface roughness. The friction sliding and adhesion friction occurs, so the curve was a sharp rise. In the middle stage of wear (3~30min), the elements distribution of the PAA was more uniform and the local micro hardness was more good than CAA, so the friction process was uniform due to furrow action (the sound less in the experiment) and the friction coefficient curve measured was more smooth. In the stable wear stage (30~40min), the
friction factor tended to be stable due to the uniform composition. Obviously, the smoothness of the friction coefficient curve depended on the uniformity of the hardness of the material.

Although the composition of the two samples were similar, but the distribution of the elements was different. Therefore, under the same friction load conditions, the loss of weight of PAA was less than CAA. Under the same friction and wear condition, the wear resistance of PAA was stronger than that of the CAA.

5. Conclusions
The microstructure and mechanical properties of the 3D printing aluminum alloy AlSi10 Mg were studied in this paper. The results were as follows:

1. The 3D printing aluminum alloy had a higher grain refinement and the alloy elements were more uniformly distributed.
2. The 3D printing aluminum alloy was higher in hardness than the cast aluminum alloy.
3. The friction coefficient curve of the 3D printing aluminum alloy was smoother, with the average coefficient of the friction factor less than that of CAA and the sliding friction had the furrow action of the adhesion friction.
4. The abrasive wear including two-body and three-body wear was the main wear form, accompanied by the abrasive melt and the 3D printing aluminum alloy was less in weight loss.

Therefore, the 3D aluminum alloy was more wear-resistant than CAST process under the same condition. Besides, the experimental data could serve as the reference for expanding the application of the 3D printing aluminum alloy.

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