

Microstructural Investigation of Inconel718 Manufactured by SLM

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Abstract. Selective laser melting (SLM) Inconel718 alloys were heat treated at two different temperatures. The as-built samples, HT950 samples, and HT1050 samples were observed by light microscopy and scanning electron microscopy, and the hardness of these samples were tested. It was found that the microstructure of Inconel 718 alloy produced by SLM was squama-like. Columnar grains appeared after HT950 treatment, and the hardness was 80% higher than that of As-built sample. Equiaxed crystal and annealing twins appeared after HT1050 treatment, and the hardness increased by 44%.

1. Introduction

Nickel-based superalloy Inconel718 exhibits high strength, toughness, fatigue life and creep resistance at elevated temperatures and corrosion resistance at high and low temperatures. Inconel718 also has the advantages that can be processed easily and have good welding performance. The above advantages make Inconel718 one of the most widely used alloys in aerospace and oil industry. Such as turbine disks, turboshaft, engines of aircraft and rockets, important parts of the offshore drilling platform etc **【1】**.

Super alloy Inconel718 is precipitation hardening alloy, mainly contains the elements Ni and Cr. The main strengthening phase is the body-centered cubic γ'' phase (Ni_3Nb), the minor strengthening phase is the face-centered cubic γ' phase (Ni_3Al), and the γ'' phase is the metastable phase turning into δ phase at high temperature **【2】**. Super alloys Inconel718 will be heat treated before use to achieve the desired microstructure and properties, the general method of heat treatment is solution treatment and aging treatment.

In the present investigation, IN718 rods were manufactured by SLM. The investigation includes the hardness and the characteristics of microstructure, directly manufactured and after two different kinds of heat treatment: solution 1h at 950°C + ageing 3h at 720°C + 3h at 620°C, air cooling; solution 1h at 1050°C + ageing 3h at 720°C + 3h at 620°C, air cooling. The aim of this research is to expand the knowledge about the microstructure of Inconel718 produced by selective laser melting and to provide a reference for its subsequent heat treatment.



2. Experimental procedures

In this research, according to the composition range requirement of SLM-ed Inconel718 alloy ,composition of samples produced by SLM is(all in wt%) :51.55 Ni, 19.62 Cr,0.17Si,5.08 Nb+Ta,3.03 Mo,1.08 Ti,1.0 Co,0.58 Al, bal Fe. Build a cylinder with a bottom area of 4 cm² and a length of 20 cm.

The metal cylinder manufactured by selective laser melting was wire-cut into a specimen of 5 mm * 5 mm * 5 mm. Samples were divided into four groups, the first group was made by direct selective laser melting (As built), the second group was aged at 720 °C +3 h at 620 °C, air cooling(HT1);the third group was solution 1h at 950°C+ ageing 3h at 720°C+3h at 620°C(HT950);the fourth group solution 1h at 1050°C+ ageing 3h at 720°C+3h at 620°C, air cooling(HT1050).

The test of hardness was completed by a Rockwell hardness test machine. In order to make the data accurate, five tests were performed on each sample, the final hardness data is the average of five tests.

Optical microscopy was used to observe the shape and the size of the grain of each sample. Scanning electron microscopy was used to observe the precipitated phase of Inconel718 fabricated by selective laser melting.

3. Experimental results and discussion

3.1. Microstructure observation and analysis

Fig. 1 (a) , Fig.2 (a) , Fig.3 (a) shows the microstructure observed by optical microscope of “as built”, “HT950”and“HT1050”, respectively. The arrow on the right of the photo shows the built orientation. As shown in Fig. 1 (a), the fish-shaped melt pool left by laser melting is clearly visible[1].And it also can be observed that columnar grains growing parallel to the direction span several melt pool layers. We boldly guess that there is elemental segregation in "as built" specimens.

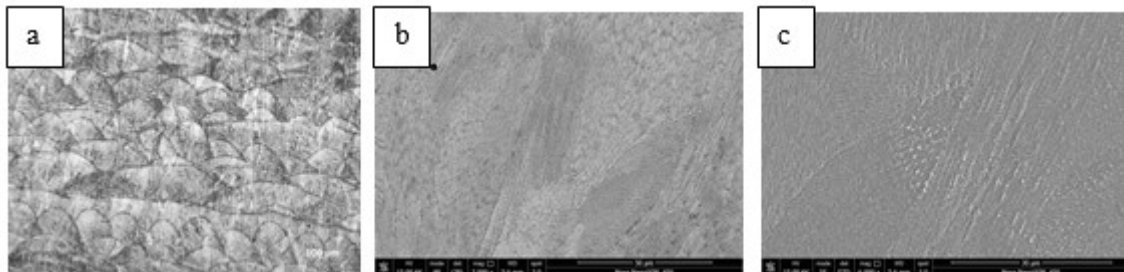


Fig. 1 OM diagram and SEM image of "As built" sample

Fig.1 (b) and Fig.1 (c) are the SEM picture of the “as built” specimens, it was observed that no precipitates were found in "as built" specimens, and columnar grains parallel to the direction of construction are also inspected. From Fig. 1 (c), the dendrites perpendicular to the construction direction can be seen, the diameter of the dendrites is about 1.5μm,while, the average dendrite arm spacing between the dendrites is about 0.1μm.The generation of such elongated dendrites suggests that the cooling rate is very high during the solidification of the melted layer. Rapid cooling easily lead to segregation of alloy components, large residual stress, prompting the formation of cracks of solidified metal, its very negative to the metal performance **【3】** .

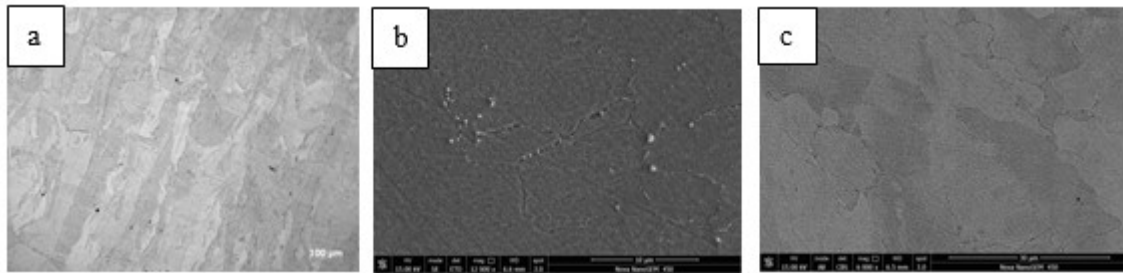


Fig. 2 OM and SEM pictures of HT950 samples

Optical micrograph of the samples solution treated at 950°C are shown in Fig. 2 (a), and SEM photographs of "HT950" are shown in Fig. 2(b) and (c). Dendrites can still be observed in the optical micrograph of "HT950", but unlike the optical micrograph of "as built", the weld pool structure has disappeared in the "HT950" and some of the porosity left in the scanning process Can be found. After the solution treatment at 950°C, the original rough grain boundaries become clear. The special micro-roughness structure in Fig. 2 (c) blocks the grain boundary sliding and improves the creep resistance of the alloy [4]. Since recrystallization of Inconel 718 alloy has just begun to occur at 950°C, columnar crystals account for the majority, elemental segregation has been eliminated to some extent. Solution treatment at 950 °C + double aging seems cannot make the matrix phase completely homogenize.

The "HT950" SEM images clearly show that some secondary phase has precipitated. These particulate precipitates mainly precipitate at the grain boundaries, as indicated by the arrows in Fig. 2(b), however, almost no precipitates were observed in the grains. The δ phase is possible to precipitate here since the δ phase occurs at a holding time of less than 100 h at a temperature range from 750°C to 1000°C [4]. The difference in lightness and darkness of Fig. 2 (c) is less noticeable, indicating an improvement in the segregation of components after the HT950 treatment.

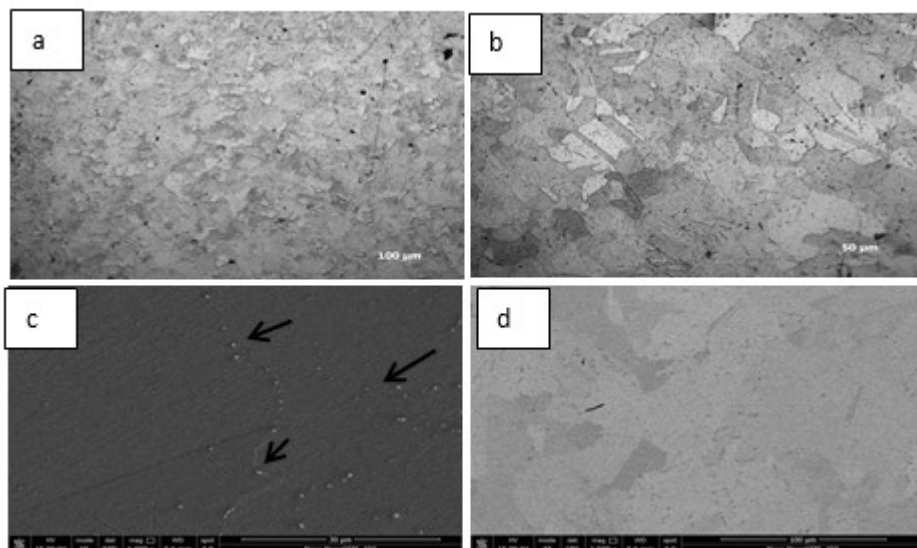


Fig. 3 OM and SEM images of SLM GH4169 alloy after HT1050 treatment

The fine, uniform equiaxed grains are seen in HT1050 sample, Fig.3 (a). The annealing twins can be observed in HT1050, Fig.3 (b). Annealed twins observed in the HT1050 samples fall into three categories: complete annealed twins that penetrate the grains, as indicated by arrow 1 in Fig. 3 (b);

annealing twins at where the grain boundaries cross as indicated by arrow 2; one end terminates in the crystal incomplete annealing twin, as shown in Figure 3 (b) arrow 3 refers 【5】. Recrystallizes on the Inconel718 alloy when held at 1050°C. In materials that are not easily slip-off, the deformation is usually done in a twin-deforming fashion. Due to the less sliding surface of nickel, in the annealing process prone to recrystallization, when the grain growth through the moving of grain boundary, the atomic layer stacking some of the planes in the wrong order by chance, there will be a coherent twin boundaries and the consequent crystal Annealing at the corner of the formation of twins.

Fig. 3 (c) and (d) is SEM images of HT1050, the second phase of the HT1050 treated samples not only precipitated on the grain boundaries but also precipitated inside the grain boundaries. Arrows 1 and 2 in Fig. 3(c) refer to the second phase that precipitates on the grain boundary, and arrow 3 refers to the second phase that precipitates inside the grain. By Fig. 3 (d) we can see that the segregation of alloying elements has been significantly improved.

3.2. Hardness data and analysis

The experimental results of hardness test are shown in Fig.4. The average surface hardness of the "as built" specimen is 22.4 HRC. When the two heat treatment process were done, the surface hardness of alloys was changed. The average surface hardness of the "HT950" specimen is 40.3 HRC; the average surface hardness of the "HT1050" specimen is 32.2 HRC, the sample after the "HT2" process is the hardest.

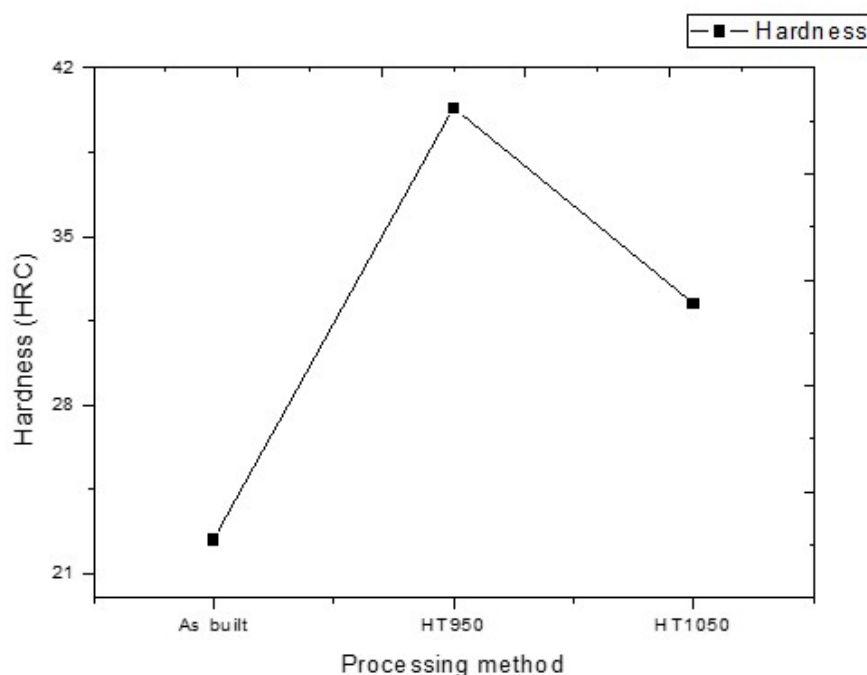


Fig. 4 Hardness of the sample in three treatments

The lowest hardness of the "as built" sample is due to the non-uniform composition of the GH4169 alloy made by SLM the coarse grain of the "as built" sample is also one of the reasons for the low hardness. So after the solution treatment at 950°C, the hardness of the sample increased by about 80%, from Fig. 2 (b), it can be seen that the spherulitic phase is precipitated in the alloy sample after 950°C.

Solution treatment and double aging treatment, and the uneven composition of the alloy has been improved, the above are two main reasons why the hardness of the HT950-treated alloy sample is improved. When the solution temperature is increased to 1050°C, the hardness of the alloy sample is 32.2 HRC, which is about 44% higher than the hardness of the "as built" sample, but lower than that of

the HT950 sample. When the solution temperature is increased to 1050°C, the precipitated strengthening phase γ'' is converted into the isomer δ phase, and the number of strengthening phases decreases 【6, 7】 , resulting in a decrease in the hardness.

4. Conclusion

(1) The inconel718 alloy structure made by SLM has a squama-like melt pool structure and coarse columnar crystals left by laser melting, and the occurrence of component segregation results in lower hardness, only 22.4HRC.

(2) After heat treatment with HT950 and HT1050, the hardness of the alloy increased by 80% and 44%, respectively. It shows that heat treatment is an effective method to improve the mechanical properties of SLM inconel718 alloy.

(3) It is recommended that the solution treatment temperature of the SLM inconel718 alloy be maintained at 900 °C ~ 1000°C in order to obtain the excellent mechanical properties of the alloy.

References

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