A Study of Microstructure, Mechanical Properties and Thermal Expansion in Super Invar Alloy Fabricated Via Selective Laser Melting

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Abstract: In this paper, the mechanical properties of the low-expansion alloy 4J32(super-Invar alloy) manufactured by selective laser melting(SLM) were studied, and the differences of the thermal expansion properties caused by the process were discussed. The results show that the appropriate selection of process parameters makes the additively manufactured super-Invar alloy exhibit higher tensile properties, which also shows a certain anisotropy. This development is mainly coming from the grain refinement due to rapid solidification and the grain selection due to process selection. The coefficient of thermal expansion of the alloy has also remained at a lower level than the existing research, showing the great advantages of additively manufactured super-Invar alloys.

Keywords: super Invar alloy; selective laser melting; tensile properties; thermal expansion properties

1 Introduction

Super Invar alloy is an iron-nickel-based alloy with excellent low expansion performance, which can even reach half of that of Invar 36 alloy (4J36) in the temperature range of 20-100℃[1]. It also has good plasticity. These properties make it one of the research hotspots in aerospace, precision instruments and other fields. However, its poor machinability and low mechanical properties limit its production and application[2]. For these reasons, this paper investigated the tensile properties and thermal expansion properties of super-Invar alloy via SLM.

2 Experimental procedure

To study the properties of additively manufactured super-Invar alloys, super-Invar powders (average particle size of 15-53μm) were used, Table 1 shown the elemental percentages. The test was carried out on the BLT210 laser printing equipment, and 15 sets of process parameters with the printing power of 200-300W and the scanning speed of 600-1000mm/s were set for experimental comparison. The tensile mechanical properties of the alloy at room temperature and 230℃ were tested at a tensile rate of 0.55mm/min on an electronic universal materials testing machine, and the experimental group with the best performance was selected to test the linear thermal expansion properties of the alloy at a cooling rate of 3K/min on dilatometer.

Table 1. Chemical composition of powders in the study(wt.%)

Elements	C	Si	Mn	P	S	Ni	Co	Fe
wt.%	0.05	0.10	0.23	0.005	0.003	31.88	5.14	Bal.

3 Result and discussion

ANALYSIS OF MICROSCOPIC TOPOGRAPHYThe microstructure of each group of test samples was characterized. The results showed that all samples have high compactness degree, and no obvious defects and cracks. The super-Invar alloy fabricated by SLM is mainly composed of austenite phases, so it exhibits a typical Invar effect on the macroscopic level. At the same time, the grain is mainly columnar grains oriented along the build direction and the average size is smaller than as-cast alloy. The reason for the above situation is that the rapid condensation of additive manufacturing technology largely avoids the growth of crystallization, and the large temperature gradient inside the melt pool leads to the growth of grains mainly along the construction direction. It's also the reason why the mechanical properties of additively manufactured super-Invar alloys show a certain anisotropy.

Analysis of tensile performance

Additively manufactured metals typically have higher strength than as-cast due to grain refinement, which is a effective way for invar alloys to improve the mechanical properties. Fig. 1(a) showed the stress-strain curve of the optimal experimental alloy at room temperature compared with the standard curve of the as-cast super-Invar alloy[3], and it is not difficult to find that the super-Invar alloy made by SLM shows higher tensile mechanical properties than the as-cast state. It also showed the difference in performance between the horizontal and build directions for the same print parameter. The tensile strength of the alloy is lower in the build direction, but the elongation is slightly higher, which corresponds to the grain preference orientation exhibited under this printing parameter.

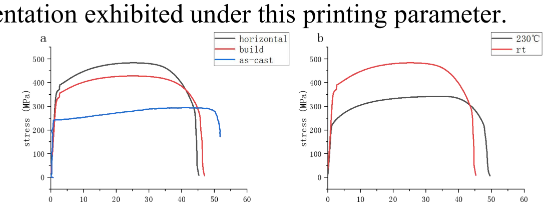

Fig. 1(a) The test stress-strain curve of horizontal and build orientation samples and the standard curve of as-cast super-Invar alloy at room temperature; (b) The test stress-strain curve of horizontal sample at room temperature and 230℃

Fig. 1(b) showed the test stress-strain curve of horizontal sample at room temperature and 230℃. The stress-strain curve in the high-temperature environment showed a significant decrease in tensile strength, which is mainly caused by the weakening of the strengthening mechanisms such as grain boundary strengthening and dislocation strengthening in the high-temperature environment. It also showed that the mechanical strengthening brought about by the SLM process cannot maintain- at high temperature.

Analysis of thermal expansion performance

Figure 2 and Table 2 shows the analysis curve of the thermal expansion test of the selected test alloy. The thermal expansion coefficient(CTE) of the super-Invar alloy used in this test has reached the level of 0.5×10^{-6}/K, showing a low thermal expansion performance far exceeding the as-cast alloy[3]. In addition, the thermal expansion curves of heating and cooling are in good agreement, indicating that the low thermal expansion characteristics brought by additive manufacturing are relatively stable and will not be affected by the temperature variation.

At the same time, it can be observed from the experimental curve that there is a rapid decline of the low thermal expansion performance of the sample over 100℃, and the average thermal expansion coefficient of the alloy in the temperature range of 20-230℃ has been consistent with the as-cast standard, which is consistent with the poor low-temperature stability of the as-cast super-Invar alloy[3].

Table 2 CTE within 20-100 ℃/20-230 ℃(10^{-6}/K)

	Heating	Cooling
20-100℃	0.4135	0.5590
20-230℃	2.7572	3.1131

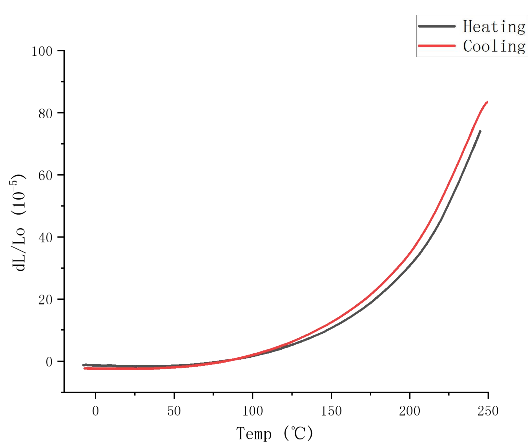

Fig 2: Test the thermal expansion test curve of sample

4 Conclusion

The super-Invar alloy fabricated by SLM has better tensile mechanical properties and exhibits certain anisotropy, which is related to grain refinement and preferential grain orientation. At the same time, the test samples showed excellent low thermal expansion performance, and reached the level of 0.5×10^{-6}/K within 20-100℃, which showed that additive manufacturing has great potential in the research direction of further reducing the CTE of super-Invar alloys.

Acknowledgments

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