The 75th World Foundry Congress
25~30 October 2024, Deyang, Sichuan, China

Effects of Powder Forming Method and Heat Treatment Process on the Microstructure and Mechanical Properties of a Ni-Based Superalloy by Laser Additive Manufacturing

Zhipeng Zhang[1, 2, 3], Jide Liu[3, *], Jianjun Wang[1, 2], Jinguo Li[3, **]
1. Key Laboratory for Anisotropy and Texture of Materials (MOE), School of Materials Science and Engineering, Northeastern University, Shenyang 110819, PR China
2. Research Center for Metallic Wires, Northeastern University, Shenyang 110819, PR China
3. Shi-changxu Innovation Center for Advanced Materials, Institute of Metal Research, Chinese Academy of Sciences, Shenyang, 110016, PR China
*Corresponding address: e-mail: jdliu@imr.ac.cn (Jide Liu), jgli@imr.ac.cn (Jinguo Li)

Abstract
In this study, the effects of powder forming method and heat treatment process on microstructure and mechanical properties of laser additive manufactured ATI 718Plus alloy were investigated. It was found that the porosity of the samples fabricated using plasma rotation electrode preparation (PREP) powders was significantly lower compared to vacuum induction melting gas atomization (VIGA). The porosity of the samples fabricated with PREP powder was controlled below 0.05% by adjusting the laser process parameters. In addition, after direct aging (DA) treatment, a large number of nano-sized γ′ phases were precipitated in the interdendritic and dendritic trunk regions, but the Laves phase was not significantly affected. After homogenization + solution + aging (HSA) treatment, the Laves phase in the alloy was basically eliminated, and a large number of needle-like η phases precipitated along the grain boundary positions, but the grains underwent obvious coarsening. The tensile results show that the ultimate tensile strength and elongation of the samples after DA treatment were significantly increased at the same time. Compared with DA samples, the tensile strength of HSA samples decreased, but the elongation significantly increased.

Keywords: laser additive manufacturing, microstructure, mechanical properties, Ni-based superalloys

1 Introduction
ATI 718Plus alloy (hereafter referred as 718Plus alloy) is a precipitation strengthened Ni-based superalloys, which is widely used in aero-engine turbine disks, compressor blades and other key components due to its excellent mechanical properties and high temperature stability [1]. Damage defects will inevitably occur during the long-term service of aero-engine, and repair technology is crucial. Laser additive manufacturing (LAM) technology can accurately manufacture and repair superalloy parts. Excellent performance of additive manufacturing alloys cannot be separated from the control of raw materials, manufacturing process and heat treatment process. Alloy powder, as a raw material for laser additive manufacturing, directly affects the strength of the repaired parts. High cooling rate can lead to significant residual stress and the formation of a large amount of Laves phase inside the parts, so it is necessary to perform heat treatment to improve the microstructure of the alloy. In addition, different heat treatment processes can obtain specific microstructures and mechanical properties under different application conditions. In this work, the effects of powder forming method and heat treatment process on the microstructure and mechanical properties of LAM 718Plus alloy were investigated.

2 Experimental procedure
The alloy powders were prepared by vacuum induction melting gas atomization (VIGA) method and plasma rotation electrode preparation (PREP) method. A forged 718Plus alloy was used as a substrate and two different alloy powders were printed using a coaxial powder feeding device with different laser process parameters. The samples prepared with the optimal process parameters were subjected to different heat treatment processes, respectively. (1) direct aging (DA) treatment, 788 °C/8 h, 55 °C/h cooling to 704 °C /8 h, followed the air cooling; (2) homogenization + solid solution + aging (HSA) treatment, 1080 °C /1.5 h air cooling +980 °C /1 h air cooling +788 °C/8 h, 55 °C/h cooling to 704 °C /8 h, followed the air cooling.

3 Result and discussion
3.1 Effect of powder forming method on microstructure
The levels of porosity in the as-deposited samples fabricated by different types of powders under the same laser process parameters are shown in Figure 1. A large number of near spherical pores exist in the samples fabricated with VIGA powders, with the maximum pore diameter reaching 200 μm. According to literatures [2], there are two mechanisms for the formation of spherical pores in the LAM process: (1) the presence of hollow powder in the original powder, which results in inert gases being trapped in the original powder and remaining inside the alloy at the end of printing. (2) A mismatch in

the input laser process parameters results in the formation of spherical holes due to gases trapped in the molten pool during deposition or gases above the molten pool being caught in the solidified tissue. However, the samples fabricated with PERP powders at the same laser process parameters have lower levels of porosity that can reach below 0.05%. This indicates that hollow powder leads to the formation of large-sized pores, which is independent of the laser process parameters. It should be noted that samples prepared from PREP powder are used in the following studies.

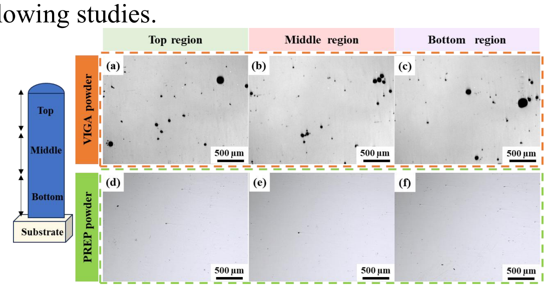

Fig. 1. Porosity levels of as-deposition samples fabricated with two different types of powders: (a, b and c) VIGA powders, (d, e and f) PREP powders.

3.2 Influence of heat treatments on the microstructure and mechanical properties

Due to the low DA treatment temperature, a large amount of Laves phase still exists in the interdendritic region, while the precipitation of short bar-like η phases at grain boundaries and a large number of γ′ phases precipitated within the grains are observed, as shown in Figure 2(a)-(d). After HSA treatment, the Laves phase is completely eliminated, and only some blocky carbides remain, but the grains have undergone significant coarsening. A large number of needle-like η phases precipitated along the grain boundaries can be observed in Figure 2(f). In addition, the γ′ phase is precipitated sufficiently by aging treatment.The room temperature tensile properties of the samples after different heat treatments are shown in Figure 3. After DA treatment, the strength of the samples increases significantly, but the plasticity remains basically unchanged. After HSA treatment, the strength and plasticity of the sample are comprehensively improved.

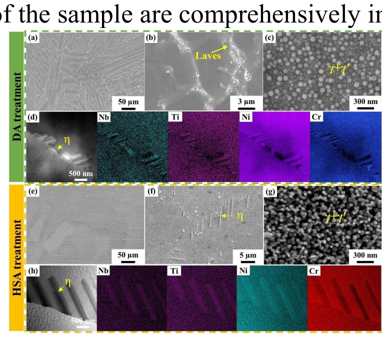

Fig. 2. Microstructure of samples after different heat treatments: (a-d) DA treatment, (e-h) HSA treatment

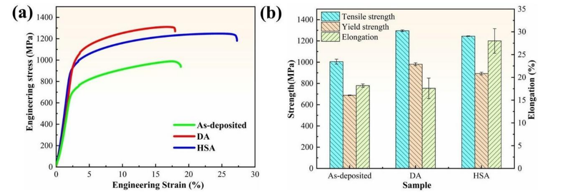

Fig. 3. Tensile properties at room temperature of the as-deposited samples and different heat treatment samples: (a) Engineering stress-strain curves, (b) Bar chart of tensile properties.

4 Conclusion

(1) Compared to PREP powder, VIGA powder has a higher percentage of hollow powder, which is the main source of porosity in LAM 718Plus alloy. The porosity of the samples fabricated with PREP powder was controlled below 0.05%.

(2) After DA treatment, the strength of the alloy increases significantly and the elongation remains essentially unchanged, which is mainly attributed to the precipitation of a large number of homogeneous nano-sized γ′ phases in the interdendritic and dendritic trunk regions. After HSA treatment, the Laves phase in the alloy was completely dissolved, leading to a significant increase in elongation. However, the coarsening of the grains and the precipitation of the needle-like η phase limited the strength of the alloy.

Acknowledgments

This work was supported by the financial support from the National Science and Technology Major Project (J2019-VI-0004-0144).

References

[1] Pickering E J, Mathur H, Bhowmik A, et al. Grain-boundary precipitation in Allvac 718Plus[J]. Acta Materialia, 2012, 60(6–7): 2757–2769.

[2] Panwisawas C, Gong Y, Tang Y T, et al. Additive manufacturability of superalloys: Process-induced porosity, cooling rate and metal vapour[J]. Additive Manufacturing, 2021, 47: 102339.