Study on the Effect of Static Magnetic Field on the Nickel-Based Superalloy Fabricated by Additive Manufacturing

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Abstract: The influence of a static magnetic field on microstructure evolution during laser direct energy deposition was studied. Our results reveal that dendrite spacing increases with increasing magnetic field flux density (MFFD). Moreover, electron backscatter diffraction results reveal that the epitaxial growth was preferred with increasing MFFD. We discuss these findings in terms of the influence of a magnetic field on melt convection and propose that an applied magnetic field effectively limits Marangoni convection.

Keywords: Ceramic mold, laser powder bed fusion, infiltration, turbine blade

1 Introduction

Directed energy deposition (DED) processes have lower production rates when compared to those of other additive manufacturing (AM) processes, such as selective laser melting (SLM) and selective electron beam melting (S-EBM). DED processes are capable of producing components with complex geometries and are particularly well suited for repairing or fabricating high value parts at low production volumes [1-3]. Hence, it is not surprising to find numerous published studies on the influence of laser energy density [4, laser source type [5], scan strategy [6] and build direction on the microstructure of AM parts by DED. Inspection of the published literature reveals some research on the solidification behavior of the melt pool during DED; however many questions remain unanswered. For example, Lee et al. [7] investigated the influence of fluid convection on dendrite arm spacing during solidification and reported an inverse relationship between temperature gradient G and growth speed R. Moreover, the relationship of simulated weld pool convection patterns to predict solidification boundary shape, cooling rate distribution, and dendrite arm spacing (DAS) was also examined. Wei et al. numerically studied heat transfer and liquid metal flow calculations in an effort to provide insight into the evolution of solidification morphology and texture during multi-layer AM processes. Further, O. Nenadl et al[8]. studied the role of solid/liquid interface on the grain orientation structure and texture based on both experimental findings and theoretical analyses.

The above discussion underscores the critical influence that solidification mechanisms in the melt pool exert on the final microstructure during DED. Inspired by results from the casting literature, researchers have proposed the idea of using a magnetic field to effect melt convection during directional solidification. For example, studies on the influence of a weak static magnetic field (in the order of 0.1 T) on the liquid melt during directional solidification suggest that a static magnetic field promotes thermoelectric magnetic convection (TEMC), and thereby ultimately influences the thermal and solute fields. Chen et al.[9] applied a 0.32 T static magnetic field during laser beam welding of austenitic stainless steel and reported a reduction in austenite grain size, and crack and thickness of brittle intermetallic compounds in the interface. Moreover, research described in reference showed that by applying a 0.3 T horizontal magnetic field the “humping” welding defect, which is analogous to “balling” in AM that leads to beading, could be suppressed and they concluded that this effect could be attributed to electromagnetic forces. In view of the above discussion, and the apparent lack of information on melt pool solidification during DED, in this research we investigated the influence of a static magnetic field on the microstructure of IN718 alloys during DED, paying particular attention to the evolution of microstructure during solidification in the melt pool. The selection of this particular material was prompted by the availability of numerous AM published studies using IN718.

2 Experimental procedure

Gas atomized IN718 powder (Staffordshire, United Kingdom) with a particle size 53 μm-150μm was used as the feed material, and laser aided direct metal tooling (DMT) was used to fabricate the specimens. A laser-aided DMT machine (InssTek, MX-450, South Korea) was used to fabricateIN718 cuboid samples with dimensions 8× 8 × 12mm. The laser scan speed used in our work was 0.85 m/min. The slicing layer depth was 0.3 mm and totally 40 layers for the sample. The scanning direction rotated 90º after each layer. It is worth pointing out that as an Ni based superalloy, the IN 718 platform has a low magnetic susceptibility ($\chi \approx 6\times10^{-4}$ SI) and hence its effect on the applied magnetic field is likely to be negligible.

The microstructures were characterized by optical microscopy (Olympus, Japan), SEM (Tescan, GAIA3, Czechia) and electron backscattered diffraction (EBSD) (Oxford, Nordlys Max2, United Kingdom) along the longitudinal cross sections (XZ plane).

3 Result and discussion

Fig. 1 show the optical microscopy of the longitudinal plane of the samples deposited at various laser energy density with various MFFDs. In all samples, black spherical pores can be observed in the microstructure. The results also showed that the porosity decreases with increasing SMF for samples fabricated at different laser energy density.

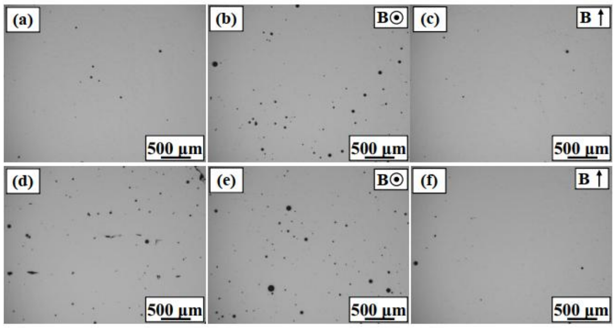

Fig. 1 Optical microscope of Inconel 718 alloys processed using different laser energy density and SMF intensities.

Fig. 2 show the EBSD maps of the longitudinal section of deposited samples with various MFFD. Fig. 2(a) and (b) are the IPF-Z maps for the samples at a constant laser energy density. EBSD map shows the grains oriented at different angles due to the variation of the thermal gradient in each layers with fine equiaxed grains with random orientations distributed along the edge of the melt pool. The pole figures also show that the texture increases with increasing MFFD from 0 T to 0.1 T.

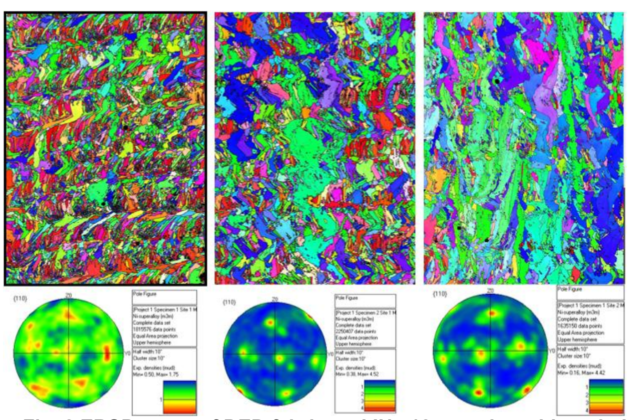

Fig. 2 EBSD maps of DED fabricated IN 718 samples with varied magnetic field intensities.

The above results demonstrate that by employing a static magnetic field (up to 0.1 T) during the DED process, the microstructure and crystallographic texture of IN718 can be modified. In the discussion that follows, it is important to note that the diameter of IN718 samples is much smaller than the substrate; therefore, the influence of the magnet on the temperature field of the substrate can be safely ignored. The change of liquid metal flow in the melt pool can easily affect the thermal distribution in and near the melt pool and alter the final microstructure. Previous studies also show that a static magnetic field can modify the melt convection and thereby alter the solidification process. During the AM process, the solidification in the melt pool mainly consists of nucleation and growth of γ cellular dendrites; the underlying phenomena have been widely studied during DED, selective laser melting (SLM) and selective electron beam melting (SEBM). On the basis of these and other studies, a superimposed magnetic field has two primary effects on melt convection. The first effect involves causing thermoelectric magnetic convection (TEMC) in the melt pool; the second one is the damping effect that a magnetic field can exert on fluid flow [10].

4 Conclusion

Influence of static magnetic field on the microstructure of IN718 alloys during DED process was studied. The following conclusions can be drawn from this work: The applied magnetic field modifies the microstructure of IN718 during DED process. With increasing MFFD, the primary dendrite spacing increases. Meanwhile, epitaxial growth leads to the formation of columnar grains through multi layers with increasing MFFD. In addition, the <110>-texture dominates the build direction and the fraction of LAGBs increases with increasing MFFD. The above results should attribute to the effect of the magnetic field on restraining the liquid convection by electromagnetic braking forces.

5 Acknowledgments

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