Characterization of Inconel 718 Fabricated through Powder Bed Fusion Additive Manufacturing

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1 Introduction

Powder bed fusion additive manufacturing (AM) is a novel technique for creating products in a layer by layer fashion under the guidance of a computer-aided design (CAD) file. The process is schematically shown in Figure 1. Metallic powder is placed on a substrate and is subsequently melted selectively by a rastering laser. The recastor blade covers the solidified layer with additional powder and the process begins again. This continues iteratively until the final product is created.

Inconel 718 is a widely used alloy in the aerospace industry because of its high-temperature mechanical properties. The main alloying elements include: nickel (56.55 wt. %), chromium (17.21 wt. %), and molybdenum (4.75-5.5 wt. %). Strength is induced from the gamma double prime (γ') precipitate of composition Ni₃Al [2].

2 Overview

The goal of this research was to identify anisotropy present in the as-deposited AM Inconel 718 sample deriving from the additive manufacturing process. Microstructures and hardness values for three different planes (Figure 2b) were examined in both as-deposited and heat treated conditions. Dendrites are detected in all as-deposited microstructures in a regular vertical pattern.

As-deposited samples are heat treated in an attempt to regain uniform hardness and microstructure. Hardness is compared between as-deposited and heat treated states. The increase in hardness seen in the heat treated material is rationalized based on a precipitated intermediate phase seen visibly in the microstructure.

3 Experimental Procedures

The Inconel 718 powder average diameter was determined to be 27 microns. Powder morphology was mostly spherical with some irregular shaped powder particles (Figure 2a). An EOSINT Model M280 machine was used with the following parameters: 285 W laser power, 80 µm laser spot size, 960 nm's scan speed, 10 µm layer thickness. The sample was fabricated into a part shown in Figure 2. The part was sectioned, and three samples were heat treated while three remained in the as-deposited state. The heat treatment consisted of a homogenization step (1050°C for 1 hour), then water quenched, followed by an aging treatment of 760°C for 1 hour.

4 Microstructure

As-Deposited

Heat Treated

5 Hardness

As-deposited and heat treated average Vickers hardness measurements are presented in Figure 4. As-deposited hardness is similar in the horizontal and vertical "long" direction at approximately 300 HV. However, significantly higher hardness is revealed in the vertical "short" direction with an average value of 489 HV. These values differ compared to the average hardness presented by Wang et al. [1] which revealed an average hardness of 365 HV independent of sample plane.

Heat treated samples exhibited average hardness at approximately 300 HV for all three planes studied. Comparatively, the average hardness for similarly heat treated wrought product is much lower at 354 HV [4].

Discussion

In the as-deposited microstructure defects such as cracks and pores are present. Cracks are induced from the intense thermal gradients produced from the additive manufacturing process. A volume contraction occurs during transformation from the liquid to solid phase creating localized residual stresses sufficient for crack generation. Porosity is a common complication in AM products. A phenomenon known as the balling effect results from semi-molten droplets that splash from the laser track. These droplets solidify on the surface of the part which can affect density after subsequent layers are added [3].

Microstructures in the vertical "long" and horizontal plane are characteristic of powder bed parts [6]. The width of the laser track (Figure 3a) and depth of the melt pool (Figure 3b) are functions of laser power. Dendrites grow along the largest temperature gradient in the melt pool. The melt pool temperature profile directly after laser pass is overlaid on the as-deposited microstructure in Figure 6 clearly showing dendrite growth toward the region of highest temperature.

Heat treated material is visually less anisotropic than the as-deposited material due to microstructural homogenization of alloying elements. Subsequent aging treatments allow for the precipitation of phases along grain boundaries. Although chemical analysis was not performed in this study, the precipitate has been identified as delta phase in a study where similar heat treated microstructures are seen [4]. The delta phase provides a strengthening effect resulting in higher hardness in the heat treated condition relative to the as-deposited state.

The vertical "short" side has an interesting as-deposited structure that has not been seen in literature. The microstructure may be an artifact from etching and will be a source of further investigation.

Conclusions

As-deposited microstructure showed a vertical dendrite morphology along build direction, which correlated to growth along the largest temperature gradient.

Heat treated microstructure revealed less anisotropy due to homogenization of alloy elements and nucleation of a secondary phase from the aging treatment.

Hardness of heat treated material was more uniform and higher than as-deposited material.

The hardness and microstructure of the as-deposited vertical "short" sample was anomalous relative to literature allowing an opportunity for further examination.

References