Macroanalysis and Hardness of Laser Aided Additive Manufactured IN100

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ABSTRACT

Additive manufacturing (AM), also referred to as “3D printing”, builds parts layer by layer, making it possible to make intricate parts with complex geometry. Plastic parts can be printed easily, but it is a challenge to print metallic parts of sound microstructures to meet the stringent requirements for aerospace applications. In this study, the characteristics of IN100 samples produced by Laser aided additive manufacturing (LAAM) were observed and compared with a cast sample. Macroanalysis showed that while the as-deposited sample has major defects such as large cracks and gas pores, the post heat-treated sample displays much better properties than both the as-deposited and cast samples. All three samples’ Vickers hardness meet ATSM5397 requirement for IN100, with the post heat-treated sample having the highest Vickers hardness measurement.

1. INTRODUCTION

Laser aided additive manufacturing is a rapid manufacturing technique that can produce net or near net shape metal components from metal powder using a high power laser a heat source [1]. In this process, material powder is deposited in thin layers and laser fuses the powder into a solid part as demonstrated in Figure 1. LAAM can help reduce the number of steps required to build a part, especially complex parts that traditional manufacturing has difficulty creating [2] [3]. LAAM offers more freedom in design, including controlled porosities and composition gradient, and reduces the manufacturing time [4].

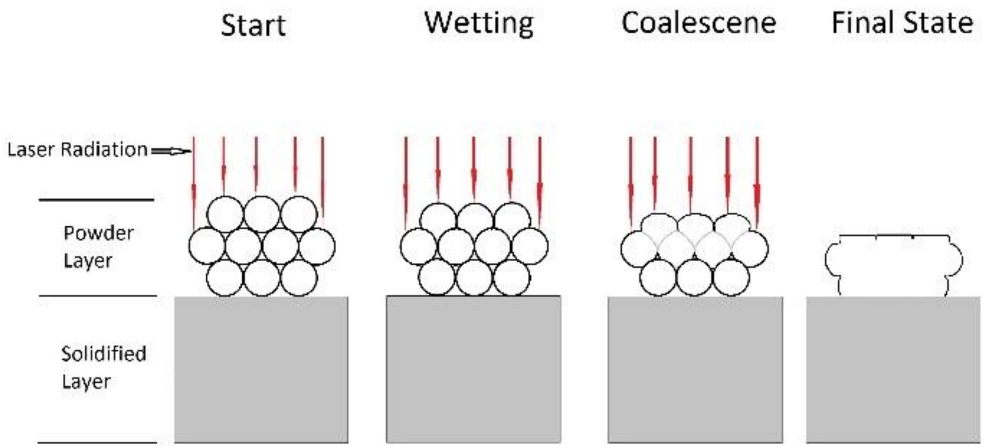


Figure 1. Laser melting process

AM was originally designed for polymers and waxes. As the technology is more developed, it is possible to produce parts from metallic, ceramic and composite materials [4]. Properties of parts produced by AM from nickel-base alloys such as IN625 and IN718 have been widely studied [5] [6] [7] [8] [9]. IN100, typically produced by casting and powder metallurgy, is rarely used for LAAM processes because of cracks from stress during rapid cooling [3] [10].

This paper will focus on features of IN100 samples produced by LAAM process. Macrostructure of the IN100 samples are studied to make comparisons between parts produced by casting and LAAM and the effects of heat treatment. Vickers hardness is also measured compared among the samples.

2. EXPERIMENTAL PROCEDURE

2.1 MATERIALS:

IN100 samples are produced by the LAAM system developed by SIMTech. A 500W, 1070nm wavelength laser system was used as the heat source. To prevent unwanted oxidization at high operating temperature, the system used argon as the shielding and powder carrying gas. Specifications of the laser used for the LAAM include beam size of 200 µm, power of 150-250 W, and scanning speed of 5-10 mm/s. IN100 gas atomized powder of average diameter of 20-45 µm was delivered by a Twin 10-C, Sulzer Metco powder feeder at 1-1.5g/min. 5-mm IN100 cast substrates were used. The same composition of the powder and substrate are shown in Table 1.

Heat treatment was performed to strengthen the samples produced by LAAM. First is a solution treatment at 1080 ºC followed by a two-step aging hardening process at 845 ºC and 760 ºC. All of the heat treatments above are carried out in an air-circulating furnace.

Table 1. Chemical Composition of IN100 powder and substrate.

Element	Al	Ti	Ni	Co	Cr	V	Mo	Fe	C	Zr	Si
Wt%	5.11	4.36	55.3	18.37	12.54	0.75	3.32	0.09	0.066	0.07	0.022

2.2 PROCEDURES:

For preparation, the samples were sectioned, ground and polished to a 0.05 µm finish. The time, speed, and abrasive size for polishing can be found in Table 2.

Samples were observed by optical microscopy (Axioskop 2 MAT) and scanning electron microscopy (Jeol JSM-5600LV). Vickers hardness was measured by Matzusawa microhardness tester at 1000 gf.

Table 2. Abrasive Size, Speed and Time for Polishing.

Abrasive Size	Speed (rpm)	Time (minutes)
9 µm Diamond Suspension	120-150	5
1 µm Diamond Suspension	120-150	3
0.05 µm Alumina Slurry	120-150	2

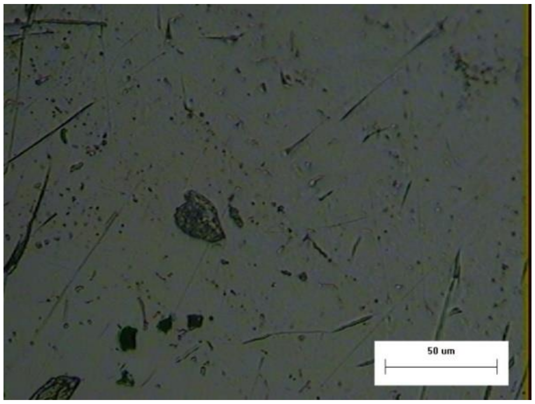
3. RESULT AND DISCUSSION

3.1 MACROANALYSIS:

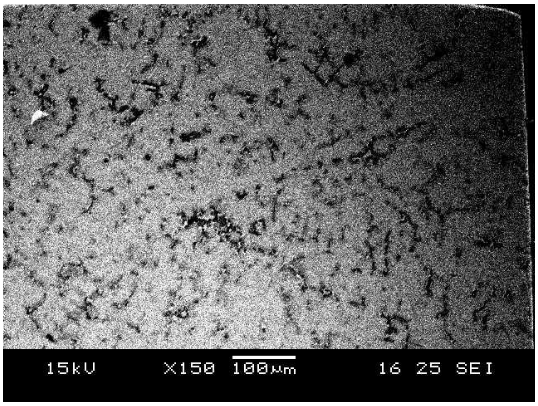
Fig. 2 shows the cross sections of cast, as-deposited and heat treated samples observed with optical microscopy. The cast sample shows few small cracks, but numerous small porosities are distributed evenly throughout the surface. This can be seen much more evidently in the SEM image in Fig .2b. It is also in Fig. 2b that we can see the equiaxed dendritic structure of the cast sample.

The as-deposited sample shows many large defects. As shown in Fig. 3 there are large cracks on the surface. This was most likely caused by the solidifying stress from rapid cooling of the layers in the laser process. Also, from Fig. 3 it can be notice that there are many circular gas porosities with diameter from 20-30 µm. This suggests that during the solidifying process there air bubble was formed by the gas remained in the melt pool [11].

The post heat-treated sample display better properties compared to the as-deposited sample. As shown in Fig. 4, there was only very few small cracks and pores of 5-10 µm diameter. Furthermore, it can be noticed that compare to the cast sample, there was very little porosity in the post heat-treated sample. This is a result from the solution treatment, age hardening processes performed on the sample as the sample lost it dendritic characteristic, and the effects of rapid cooling were reduced [3].

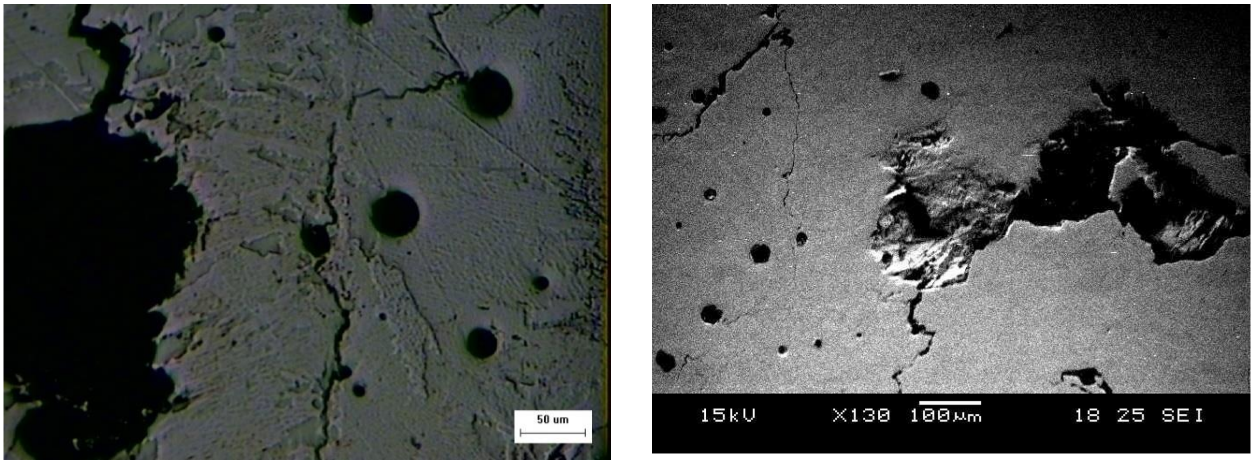


a)



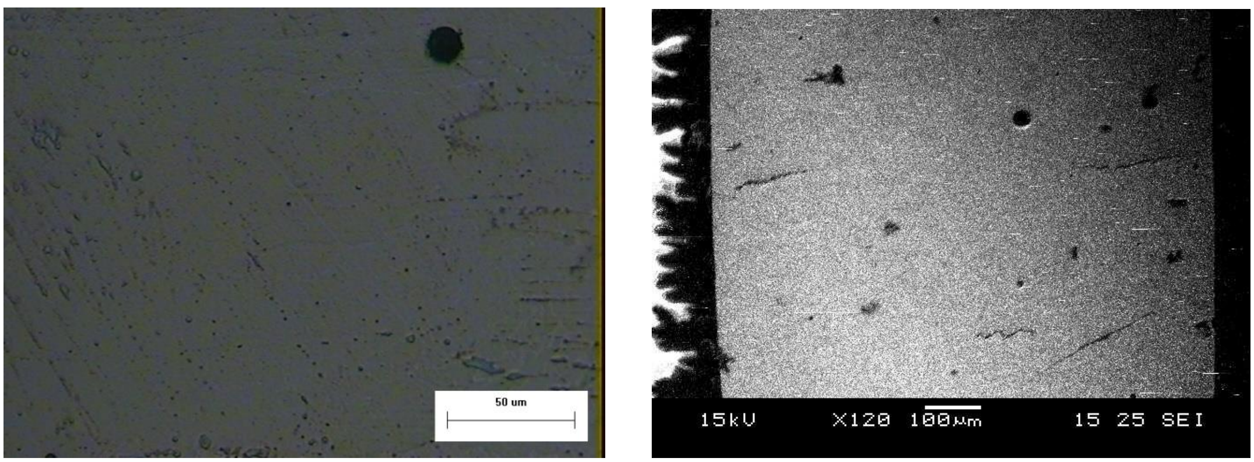
b)

Figure 2. Cross section view of cast sample a) with optical microscopy b) with SEM



a) b)

Figure 3. Cross section view of as-deposited sample a) with optical microscopy b) with SEM



a) b)

Figure 4. Cross section view of post heat-treated sample a) with optical microscopy b) with SEM

3.2 Vickers Hardness:

Table 3 shows the Vickers hardness of the three samples. Of the three samples, the post heat-treated sample has the highest Vickers hardness while the as deposit has the lowest hardness. This can be partly explained by the porous structure of the as-deposited sample. In contrast, the post heat-treated sample not only has very few porosities, it also has more reinforcement particles formed during the heat treatment processes [3]. This increases the hardness of the material by enhancing the dispersion-strengthening effect in the matrix and decrease the average grain size of the material [12]. Despite the variation, all three samples meet the hardness specification 5397 for IN100 [13] [14].

Table 3. Vickers hardness measurements.

Samples	Cast	As-deposited	Post Heat-treated
Vickers Hardness	455.06	438.28	461.72

4. CONCLUSION

LAAM process followed by heat treatment can produce IN100 part with good properties even when compared with cast part. The heat treatment processes reduces both the number of porosities and cracks in the material. At the same time, they also increase the formation of strengthening phase in the material and thus yield a higher hardness. Although more study in LAAM produced material needs to be conducted to further improve the technology, the result shows LAAM has the capability to produce parts with stringent requirement for industries in the future.

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