Microstructure and Microhardness of 17-4 PH Stainless Steel Made by Laser Metal Deposition

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***Abstract*— Laser metal deposition (LMD) is an additive manufacturing process. Unlike conventional manufacturing process which is subtractive, LMD produces part layer by layer from the ground up and has been used to fabricate fully dense components using a variety of metallic powders. This paper investigates the evolving properties of laser deposited 17-4PH stainless steel. The microstructure was martensitic with a dendritic structure. The average microhardness of the samples was found to be less than their wrought counterpart.**

***Index Terms*—Additive manufacturing, Laser metal deposition, Microstructure, Microhardness.**

I. Introduction

Although Additive manufacturing (AM) has gather a lot of attention in recent time, the technology was first introduced over a decade ago [1], [2]. AM refers to a group of processes that manufacture fully dense and functional components directly layer by layer using a three dimensional (3D) model data. AM comprises of several technologies, these different technologies generally have similar operating principles [3]. However, they may differ in various way such as the way successive layers are stacked, the energy source used for melting and even type of materials they process. Some of the common technologies available include Stereolithography, Fuse Metal Deposition (FMD) Selective Layer Sintering (SLS) and Selective Laser Smelting (SLM), 3D printing (3DP) and Laser Material Deposition (LMD) to mention a few [4]. 3DP machines are generally less expensive when compared to the other AM technologies. Machines that fall under this category utilizes a print head almost identical to that of an inkjet printer for material deposition [3]. Common applications includes prototyping and direct part production.

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Selective Laser Melting (SLM) is many ways similar to SLS, one distinct difference between both technologies is in the material they can process. SLM can be used to a variety of materials ranging from metallic to ceramic, while SLS machines are more suited for fabricating polymer material. Parts are produced by melting powder deposited on a platform or powder bed using a high power energy source such as a laser or electron beam [5].

Similarly, Laser material Deposition utilizes a laser technology, however, in LMD parts are fabricated by delivering metallic powder or wire in the path of the laser beam. A very important benefit of LMD machines is that they can also be used for repair works [6] and also used to fabricate complex structures. Several metallic materials have been successfully processed using this technology these include Stainless steel [7], [8], Titanium [9], [10], Aluminum [11], Inconel [12], [13].

The aim of this study is to investigate LMD 17-4PH stainless steel with the intention to produce a fully dense part with properties identical or better than conventionally produced 17-4PH stainless steel (SS) parts. The microstructure and microhardness of the laser SS processed part will be analyzed.

II. Experimental Method

The substrate used in this research was 316 stainless steel coupons with dimension of 100 × 100 × 10 mm. while the powder used was gas atomized 17-4PH stainless steel with a particle size of 45-90 µm and the powder was purchased from TLS Technik GmbH & Co. (Germany). The elemental composition of the 17-4PH SS powder is presented in Table I.

TABLE I
Composition of 17-4PH Stainless steel

Element	Composition (%)
Fe	73.7
Ni	4.4
Cr	16.4
Cu	4.0
C	0.01
Others	Balance

The substrate was cleaned using a sand blaster and then acetone was used for further cleaning in order to remove and grease on the surface of the substrate. The LMD machine used to carry this experiment consist of a laser deposition head attached to a Kuka robotic arm as shown in Fig. 1.

Fig. 1. Laser metal deposition machine

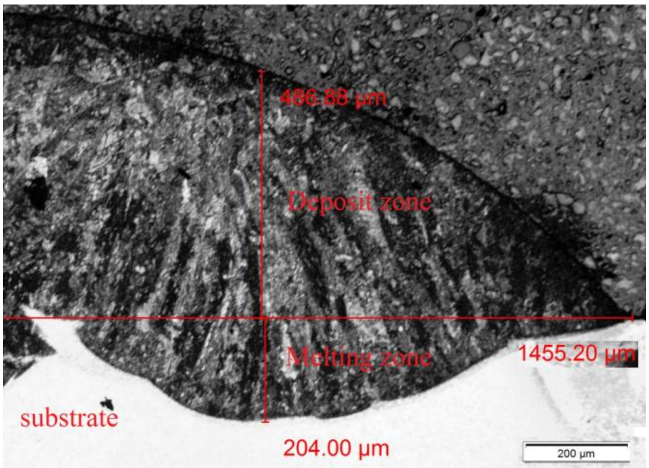

Fig. 2. Overall view of sample 1

The machine works by creating a melt pool on the substrate by the laser attached to the deposition head and the 17-4PH powder was injected into the melt pool forming a metallurgical bond thereby producing a solid metallic deposit as the molten material solidifies. Multiple tracks (5 tracks) are deposited for each sample produced. After deposition was completed the samples were prepared for characterization. First the samples were cleaned and then cut at right angle to the direction of deposition. The sectioned samples were metallurgical prepared consistent with the ASTM standard. The microhardness profile of the samples from the cladded region to the substrate was measured using Vicker's hardness tester. The dwell time and load was set at 15 s and 200 g respectively, while the space between indentations was kept at 0.11mm. Samples for optical imaging analysis were etched using waterless Kalling's etchant (5 g cupric chloride, 100 ml hydrochloric, and 100 ml ethanol). The experimental matrix is presented in Table II.

TABLE II
EXPERIMENTAL MATRIX

	Scanning Speed (m/s)	Laser Power (kW)	Powder Flow Rate (l/s)	Carrying Gas (l/s)	Overlap (%)
Sample 1	1.2	2.4	2.0	2.5	50
Sample 2	1.0	2.4	2.0	2.5	50

III. RESULTS AND DISCUSSION

Fig. 2 shows the overall view of the laser deposited 17-4PH stainless steel processed with a laser scan speed of 1.2m/s. The deposition is defect free and shows the distinctive overlapping structure. Both samples are fully dense showing no indication of porosity or solidification cracking. The melt depth of sample 1 and sample 2 are 0.204 mm and 0.154 mm respectively.

Dilution (D) is an important property in LMD, it is degree at which clad and the substrate intermix. The percentage dilution can be calculated using the following equation [14]:

$$D = \left(\frac{Am}{Ac + Am} \right) X\ 100 \qquad (1)$$

Where Am is the cross sectional area of the melted substrate and Ac is the cross sectional area of the deposit zone. The degree of dilution in the two samples was visually analyzed and it was observed that sample 1 had a higher degree of dilution compared to sample 2.

Final microstructure of LMD components depends to a large extent on the temperature gradients and solidification conditions. The optical micrograph of the deposited zone of samples 1 and sample 2 is shown in Fig. 3(a) and 3(b) respectively.

Laser processed parts have a finer grain structure compared to parts produced through conventionally methods such as cast or wrought products. This finer grain structure observed in LMD is as result of the fast solidification. The microstructure of the sample is martensitic with a dendritic grain structure and the dendritic growth is parallel to direction of the heat flow, this dendritic microstructure is common in laser processed 17-4 PH [15].

The average microhardness of the samples is presented in Fig. 4. The average microhardness of the 316 substrate was about 148Hv. The microhardness of the deposit zone of the laser process was approximately 204 Hv for sample 1 and 244 Hv for sample 2. These values are much lower than of wrought 17-4 PH steel (Condition A).

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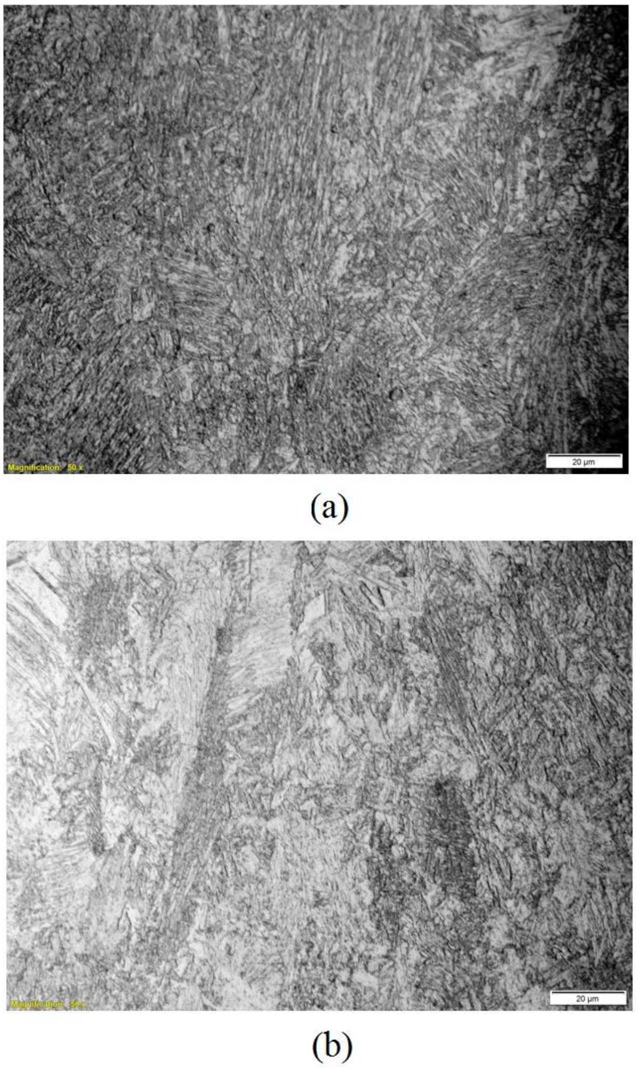

Fig. 3 Optical micrograph of the deposit zone of (a) sample 1 (b) sample 2

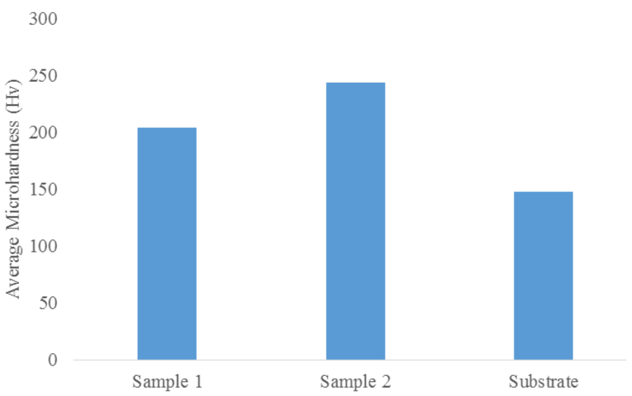

Fig. 4. Average Microhardness

IV. Conclusion

The microstructure and microhardness of laser processed 17-4PH stainless steel has been investigated. The microstructure was analyze using and optical microscope and a Vickers hardness tester was used to obtain the hardness profile. The LMD samples were defect free, showing no signs of cracks or porosity and the microstructure was martensitic with a dendritic growth structure. The microstructure and microhardness of laser processed 17-4PH stainless steel has been investigated. The microstructure was analyze using and optical microscope and a Vickers hardness tester was used to obtain the hardness profile. The LMD samples were defect free, showing no signs of cracks or porosity and the microstructure was martensitic with a dendritic growth structure.

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Acronyms

AM – Additive Manufacturing
DZ – Deposit Zone
LMD – Laser Metal Deposition
MZ – Melting Zone
SS – Stainless Steel

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