Influence of laser power on microstructure of laser metal deposited 17-4 ph stainless steel

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Abstract **–** The influence of laser power on the microstructure of 17-4 PH stainless steel produced by laser metal deposition was investigated. Multiple-track of 17-4 stainless steel powder was deposited on 316 stainless steel substrate using laser metal deposition, an additive manufacturing process. In this research, laser power was varied between 1.0 kW and 2.6 kW with scanning speed fixed at 1.2 m/s. The powder flow rate and the gas flow rate were also kept constant at values of 5 g/min and 2 l/min respectively. The microstructure was studied under optical microscope and it revealed that the microstructure was dendritic in structure with finer and lesser δ-ferrite at low laser power while the appearance of coarse and more δ-ferrite are seen at higher laser power.

1. Introduction

17-4 PH stainless steel is a martensitic characterized stainless steel that finds numerous applications in nuclear industries, pulp and paper industries, food processing equipment, turbine blade design, centrifugal compressor impeller blade, biomedical, oil and gas industries [1]. The microstructure of 17-4 PH stainless steel consists of delta (δ) ferrite, austenite, copper precipitates and martensite. Basically ferrites are the function of the magnetic properties in stainless steel grades [2, 3]. Martensite is the primary microstructure of 17-4 PH stainless steel before subsequent heat treatment and cooling that is why it is classified as "Martensitic Stainless Steel". This particular martensite is largely dependent on the processing parameters used for its fabrication such as heat treatment and the rate of cooling [4, 5].

Additive manufacturing is a modern method of fabrication process which is used in producing functional engineering metallic components by adding material one layer at a time from computer aided design (CAD) model data [6]. There are various types of additive manufacturing technologies, they include: vat photopolymerization (stereolithography), fused deposition modeling, selective laser sintering, electron beam melting, laminated object manufacturing and Laser metal deposition [7].

Laser metal deposition is a unique additive manufacturing process where metallic components are manufactured by deposition of processed metallic powder layer by layer on the melt pool created on the substrate by high intensity laser beam. The metallic powder is deposited on the melt pool on a substrate which after solidification, a solid material is formed according to the 3D CAD model data in the presence of inert gas such as argon or helium, in order to prevent the melt pool from oxidizing by reacting with atmospheric oxygen [8]. The process is guided by processing parameters such as laser power, scanning speed; powder feed rate, laser spot diameter and other important parameters based on various objectives. This process is unique because, it can be used to repair worn out important engineering components parts that were difficult to repair in the past [9]. The flexibility of laser metal deposition process permit the use of high variety of materials such as metals, composites and alloys such as Titanium alloys [6,10-12] , stainless steel [13] aluminum and aluminum alloys [14]. The influence of scanning speed on the microstructure of 17-4 PH stainless steel was studied by *Bayode et al,* [13]. Multiple tracks of 17-4 PH stainless steel of two samples was deposited on 316 stainless steel at laser power fixed at 2.4 KW with scanning speed altered between 1.0 m/s and 1.2 m/s respectively. The microstructure was studied by optical electron microscopy. It was deduced that the microstructure was martensitic with dendritic structure with no sign of crack and porosity.

The aim of this study is to investigate the influence of laser power as on the evolving microstructure of 17-4 PH stainless steel, using the laser metal deposition process.

2. Experimental Method

Gas atomized 17-4 PH stainless steel powder with particle size range between 40-95 µm, was deposited on the 316 stainless steel substrate with dimensions of 10x 10 x 10 mm. As a precaution before the deposition process, the substrate was sand blasted and cleaned with acetone so as to achieve a desirable surface ready for the deposition process. During the deposition process, multiple tracks (6 tracks) at 50% overlap percentage of 17-4 PH stainless steel powder was deposited per sample of five (5) through the coaxial powder nozzles into the melt pool created by the laser on the 316 stainless steel substrate after which a metallurgical bond is formed between the deposit and the melt pool after solidification. The laser head was attached to a kuka robot which controls the deposition process. The laser metal deposition process was achieved through the use of Nd-YAG laser with laser maximum capacity of 4.0 kW. The set-up of the laser metal deposition process is shown in figure 1.

Figure 1. Laser Metal deposition machine set-up

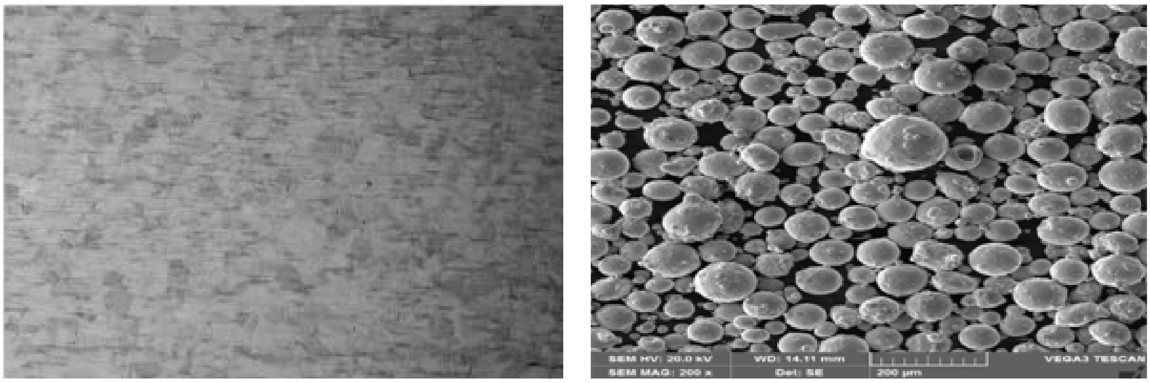
Laser power was altered between 1.0 kW to 2.6 kW. The fixed parameters were the scanning speed of 1.2 m/min, powder flow rate of 5 g/min and gas flow rate of 2 liters/min. The experimental matrix is presented in table 1. After the deposition process, the sample was dissected and prepared for characterization. The specimen was dissected into five samples perpendicular to the direction of deposit. Specimens were mounted in resin, grounded, polished and etched according to stainless steel metallographic sample preparation. The samples were etched using waterless Kalling`s reagent which comprises of 5 g cupric chloride, 100 ml hydrochloric acid and 100 mm ethanol. After etching, the five samples were studied under optical microscopy in order to study the microstructure to determine how the laser power affects the microstructure of each of the samples.

Table 1. Experimental Matrix

Sample	Laser Power (KW)	Scanning Speed (m/min)	Powder flow rate (g/min)	Gas flow rate (liters/min)	Laser spot size (mm)
1	1.0	1.2	5.0	2.0	2.0
2	1.4	1.2	5.0	2.0	2.0
3	1.8	1.2	5.0	2.0	2.0
4	2.2	1.2	5.0	2.0	2.0
5	2.6	1.2	5.0	2.0	2.0

3. Results and Discussion

The microstructure of the substrate 316 stainless steel is shown in figure 2a. The morphology of 17-4 PH stainless steel powder used in this study is shown in figure 2b. The deposits consist of multiple tracks (6 tracks) per sample with hemi-spherical shape. The optical micrograph of single track sample 1 is shown in figure 3, indicating the deposit zone, dilution zone and heat affected zone. The heat affected zone appears to be not pronounced. The microstructure of the substrate at the heat affected zone appears globular due to long period exposure to temperature in form of heat flux. This particular globular name comes from its coarse appearance.



(a) **(b)**

Figure 2. The (a) Microstructure of substrate (b) Morphology of 17-4 PH stainless steel powder.

The microstructure of 17-4 PH stainless steel deposit appears to be martensitic and dendritic in shape which are formed predominantly along the heat flow direction during solidification process. The black grains are the δ – ferrite while the white nanoscale appearance is the martensite. According to metallurgists, during solification after heat treatment of 17-4 PH stainless steel alloy, two major microsctructure emerges, which are the body centered cubic (BCC) delta δ – ferrite and face centered cubic (FCC) austenite. Allotropic transfomation takes place during further cooling which causes the face centered cubic (FCC) austenite to transform to body centered tetragonal (BCT) demartensite [4] but not all the austenite transform totally to martensite. That part of austenite that did not transform to martensite which are reffered to as retained austenite are observed to be formed along with the martensite in form of matrix [5] .

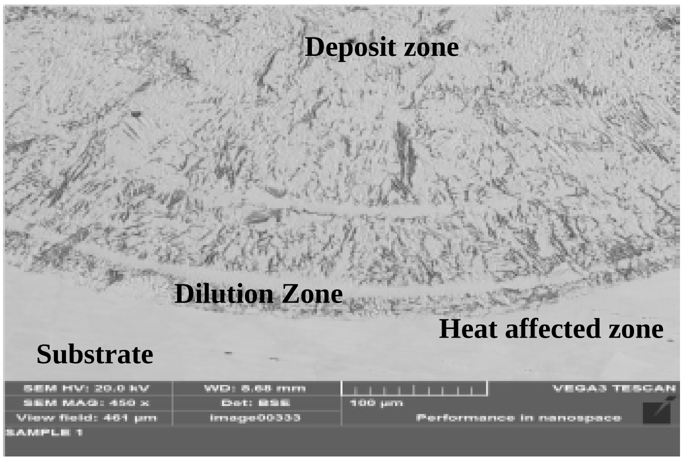
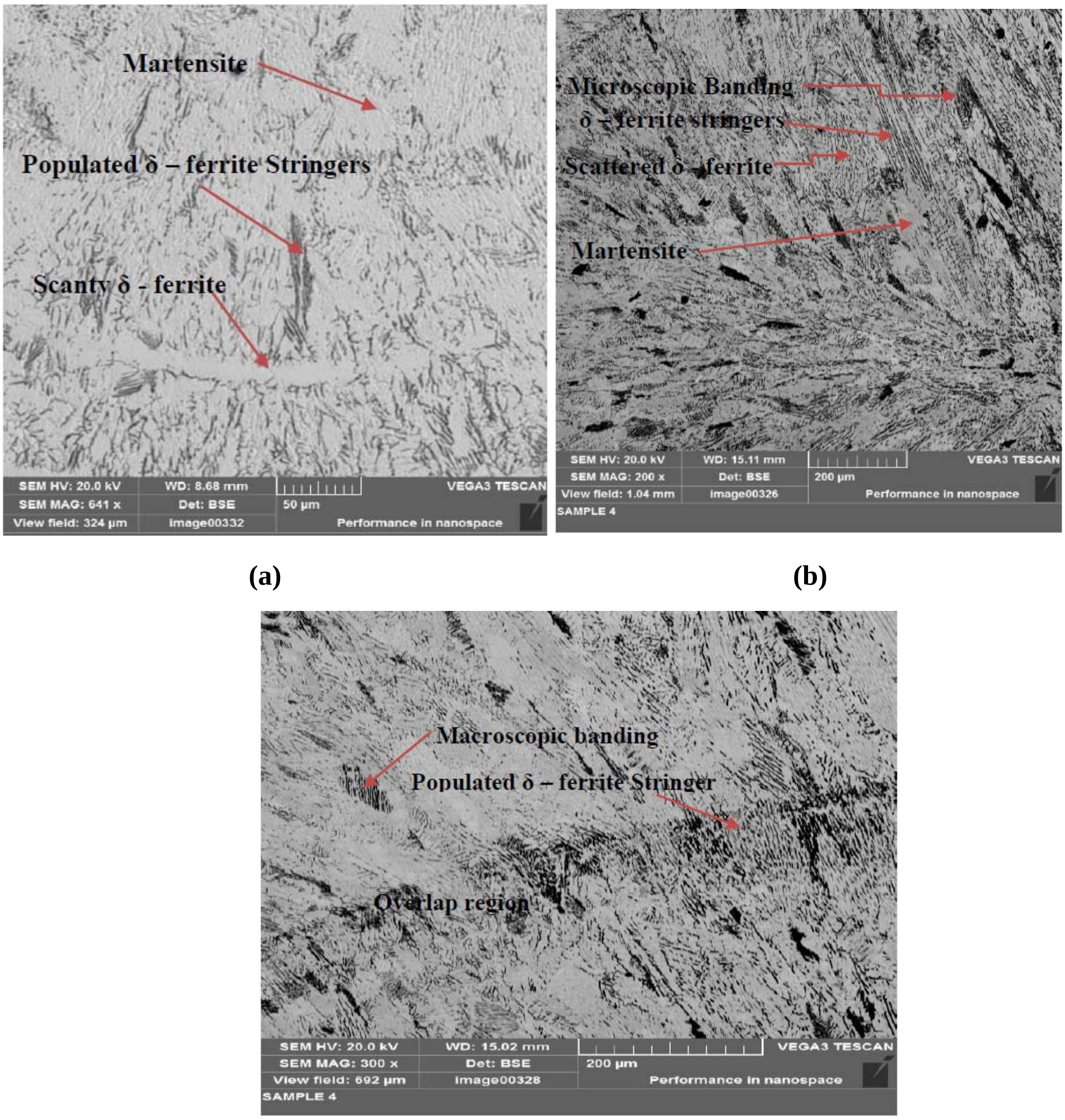


Figure 3. Micrograph of Sample at a laser power of 1000 W

They have the whitish-grey appearance as seen in the microstructure while the martensite are the white appearance part. It was observed that at low laser power, the microstructure of the 17-4 PH stainless steel deposit exhibit fine dendritic appearance (BCC δ – ferrite) which becomes coarse in samples deposited at high laser power with evidence of macroscopic banding. It is also observed that microscopic banding occurred in all sample due to the fact that it is a multiple track deposit which is as a result of the re-melting of the previous layer by the subsequent layer. The microstructures at different laser power are presented in figure 4a and 4b. It can be observed that more δ – ferrite strings are more populated at high laser power and less populated at low laser power this is because of the slow cooling rate at high laser power which promotes the nucleation and growth of more δ – ferrite and by the time the cooling reaches room temperature after the martensite is formed, it will be seen that the δ – ferrite (dark appearances) had already dominated most areas in the microstrcture as compared to martensite (whitish-grey). At the overlapping region, a band-like appearance is observed, this is caused by the re-heating of the latter part deposit on which the new deposit lay on. At that particular region, δ – ferrite are more populated and scattered at high laser power due to re-heating activity that had taken place in that region and becomes less populated at lower laser power shown in figure 4c. At the dilution zone, just before the heat affected zone on the substrate, the microstructure at that region appear to be acicular and are populated with δ – ferrite along the edge boundary of each track. White nanoscale precipitate appearance are observed between primary dendrites which are referred to martensite with niobium rich carbides.



(a) **(b)**

(c)

Figure 4. The (a) Microstructure of sample at low laser power 1000 W **(b)** Microstructure of sample at high laser power 2200 W. (c) Micrograph of Overlap region at high laser power 2200 W.

4. Conclusion

17-4 PH stainless steel has been deposited on 316 stainless steel substrate with varying laser power that ranges between 1.0 KW to 2.6 KW with scanning speed of 1.2 m/min, powder flow rate and gas flow rate of 2.0 g/min and 2.0 liters/min respectively. The effect of laser power on the microstructure and macrostructure were studied. The microstructure of deposits was martensitic with dendritic growth structure.

The effect of the laser power on the microstructure of the deposit was examined. The microstructure of deposit at high laser power appears coarse due to high laser intensity which results in low cooling rate as compared to microstructure of deposit at low laser power. At high laser power the microstructure appears coarse which can be seen as thick δ – ferrite stringer. Microstructure of deposit at low laser power appears as fine δ – ferrite stringer with dendritic structure because of low laser intensity which results into fast cooling of the melt pool after deposition. The δ – ferrite grain structure formed during cooling do not have time to form due to fast cooling resulting from not enough heat. It was also observed that there were accumulations of columnar δ – ferrite string-like dendrite at the dilution zone just before the substrate. The laser metal deposition samples were defect free with no signs of crack.

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