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Effect of Powder Flow Rate on Surface Finish in Laser Additive Manufacturing Process

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Abstract. Laser metal deposition process is an additive manufacturing process that can produce three-dimensional part through material addition. It that belongs to the class of directed energy deposition. This technology is still fairly new and some of the physics of the process is not fully understood. In this study, the influence of the processing parameter, namely: the powder flow rate, on the resulting physical property of laser metal deposited titanium alloy powder on titanium alloy substrate was carefully investigated. The powder flow rate was varied between 1.44 g/min and 7.2 g/min while the laser power, the gas flow rate, the laser spot size and the scanning speed were maintained at constant values of 3 kW, 2 l/min, 2mm and 0.004 m/s respectively. The laser metal deposition experiment was conducted using a 4.0 kW Nd: YAG laser. The surface roughness was measured using Jenoptik surface analyzer. The results showed that the surface roughness increases when the powder flow rate was increased. The minimum average surface roughness value of 4.5 µm was achieved at the lowest powder flow rate of 1.44 g/min. The low roughness value obtained at lower powder flow rate could be attributed to proper melting of the powder at these settings.

Key Words: Additive manufacturing, laser metal deposition process, Nd:YAG laser, surface roughness,Ti6Al4V

1. Introduction

Laser material deposition (LMD) is an important additive manufacturing technology for producing solid object from the three dimensional (3D) computer aided design (CAD) data of the object. This is achieved by building up materials layer after layer by following the path generated by the CAD data [1]. In adaptation to the ability of the process to fabricate new 3D components, it can also be used to repair a high valued component which used to be difficult to repair [2, 3]. The LMD process also offer great flexibility in allowing the use of more than one materials at the same time makes it possible to fabricate components that is made of composite material as well as compositionally graded material [4, 5]. Laser metal deposition technology is still fairly new and a number of unresolved issues still exist. The key processing parameters in the LMD technology play important role in the and proper processing parameters control is key at reducing the cost of the manufacturing process such as the need to eliminate secondary finishing operations [6-10]. LMD process is a contactless manufacturing technology that makes it an important technology for processing difficult to machine materials. A number of studies have been reported in the literature that which relates the influence of processing parameters to the properties of the material produced using the LMD process [11-15]. The processing parameters in the LMD process were found to have great influence on the evolving properties of the deposited materials. In one of the authors' previous work, the influence of power density on the resulting surface roughness of Titanium alloy produced using LMD process was investigated. This study showed that, surface finish improves as the laser

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power density was increased. A number of industries are interested in titanium and its alloys due to the excellent properties of this alloy which include low density, high strength-to-weight ratio, and excellent corrosion resistance. such industries include the aerospace, chemical, petrochemical, marine and medical industries [16]. Ti6Al4V is an important Titanium alloy often termed the workhorse in the industry due to its vast application area [17]. Laser metal deposition process is an important alternative manufacturing process for difficult to machine material like titanium and its alloys. The laser metal deposition process parameters need to be properly controlled in order to control the properties of the deposited materials. To further build on the past study [18], this study investigates the influence of powder flow rate on the surface finish produced during the LMD process. Ti6Al4V was used in this study due to its excellent mechanical properties and bio-compatibility which make it useful in aerospace and biomedical industries [19].

2. Experimental Methods

The substrate used in this study is an annealed 5mm thick 99.6% pure Ti6Al4V sheet has supplied by VSMPO-AVISMA Corporation in Russia. Before the deposition process was commenced, the substrates prepared through sandblasting and then washed in acetone and dried. The reason for this preparation was to make the surface of the substrate to become less shining which is desirable for better laser absorption. The Ti6Al4V powder is also 99.6% pure and of particle size of between 120 and 350 µm. The laser that was used in this study is a 4.0 kW Nd: YAG laser attached to the end effector of a Kuka robot. The laser power, the scanning speed, and the gas flow rate were maintained at 3.0 kW, 0.004 m/s, and 2 l/min respectively. The laser spot size was also kept at a value of 2mm which is at a focal length of 195mm above the substrate. Powder flow rate was set between 1.44 g/min and 7.2 g/min. A glove box was provided and filled with argon gas to keep the oxygen at a low level and also as a powder carrying gas. The deposited samples needs to be prevented from environmental attach as it could also result in degrading the surface finish. The laser was used to create a melt pool on the substrate where the Ti6Al4V powder was delivered during the laser metal deposition process. The powder was introduced to the melt pool using coaxial powder delivery system that iv also attached to the end effector of the robot. The schematic diagram of the laser metal deposition process is shown in Figure 1.

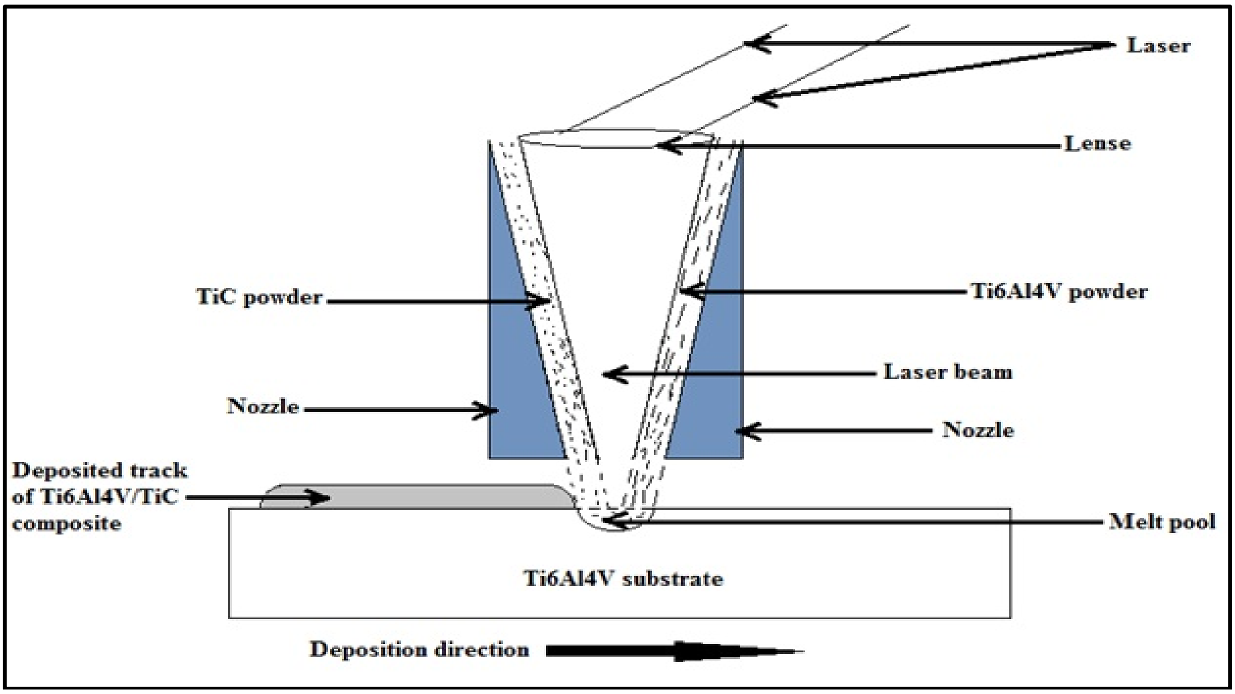

Figure 1**:** Schematic diagram of the laser metal deposition process [19]

After the deposition experiment was completed, the samples produced were thoroughly cleaned using acetone so as to remove any loose powder particles and dirt that is found attached to the samples that could cause error in the surface roughness measurements. After the samples were cleaned, the surface roughness measurement was carried out with the Jenoptik surface analyzer (see Figure 2) which is equipped with Hommelmap 6.2 software. The measurement was conducted using measuring condition according to 'BS EN ISO 4288:1998' standard [20]. The measuring conditions used are as follows: the effective measuring length is 4.8 mm, the cut-off length is 0.8 mm, sliding speed is 0.50 mm/s and the measuring range employ is 400 µm. The measurement was taken five times on each sample and the arithmetic mean of the surface roughness profiles (Ra) for each of the samples was recorded.

Figure 2 Photo of Jenoptik surface analyzer used in this study

3. Results and Discussions

Table 1 presents the average surface roughness at each set of processing parameters. Figure 3 shows the graph of the average surface roughness versus powder flow rate. The surface roughness was seen to increase as the powder flow rate was increased. At lower powder flow rate, the available laser power was able to efficiently melt the deposited powder which results in creation of bigger melt pool. Bigger melt pool takes longer to solidify and cool down which results in production of smoother surface finish. By increasing the powder flow rate, there is improper melting of the delivered powder since the laser power was fixed.. This results in rougher surface. Also, the melt pool that was created at higher powder flow rate was smaller due to improper melting of the powder which makes it to solidified more quickly thereby contributing to poor surface finish. The importance of this study helps to determine the proper combination of processing parameters so the desired surface finish can be achieved . This will in turn have impact on the economy of the entire process. With the use of proper processing parameters, Requirement for expensive secondary finishing operation will be eliminated when the LMD process is use to fabricate 3D product and in repair of parts.

Table 1. Results of average surface roughness

Sample No.	**Powder flow rate (g/min)**	**Average surface roughness (µm)**
PM	-	0.42
A	1.44	4.5
B	2.88	7.7
C	4.32	11.9
D	5.04	15.2
E	5.76	19.2
F	7.2	27.8

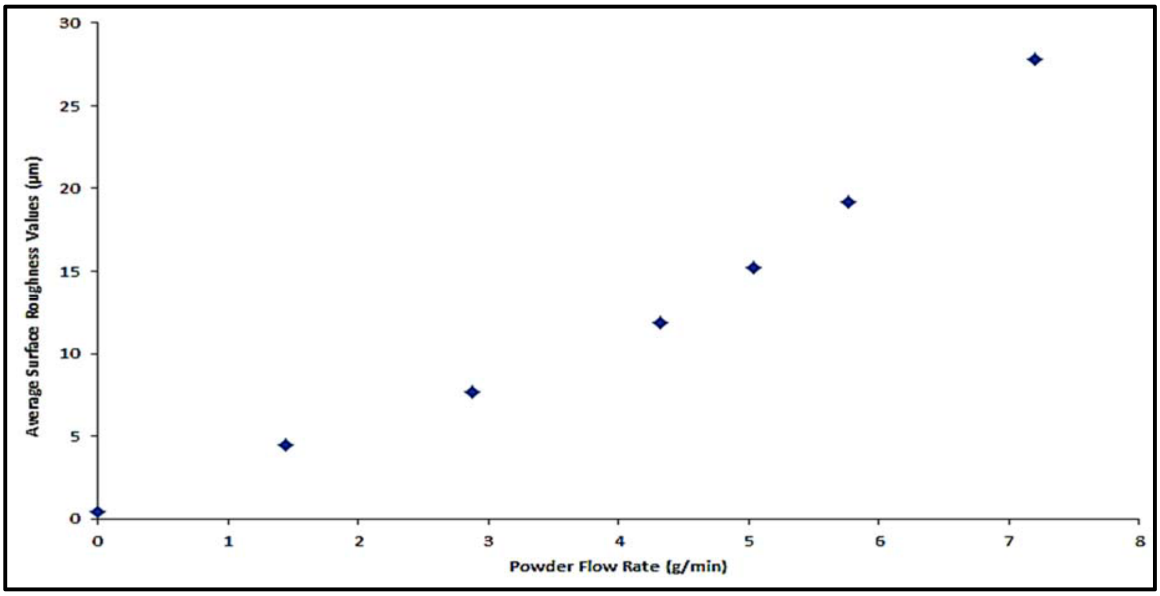

Fig. 3: Graph of average surface roughness against powder flow rate

4. Conclusions

This paper investigated the influence of powder flow rate, an important processing parameter in laser metal deposition process, on the quality of surface finish produced when titanium alloy, Ti6Al4V was produced with laser metal deposition process. The powder flow rate was varied between 1.44 to 7.2 g/min. Other processing parameters were kept constant through the deposition process. The results obtained in this research work revealed that, the powder flow rate has a significant influence on the quality of surface finish achievable in the laser metal deposition process. It was found that, the quality of surface finish improves with decreasing the powder flow rate. It can be concluded that the powder flow rate should be carefully controlled during the laser metal deposition process so as to reduce the need for secondary finishing operations which could be very expensive and affect the economy of the process. This study is important most especially in the aerospace industry, where highly complex parts are produced and also in product repair and remanufacturing process.

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