

# Characterisation of laser metal deposited titanium and molybdenum composite

Stephen A Akinlabi<sup>1a</sup>, Madindwa P Mashinini<sup>2a</sup>, Oluseyi O Ajayi<sup>3c</sup>, Abiodun A Abioye<sup>4c</sup>, Samuel O Fatoba<sup>5b</sup> and Esther T Akinlabi<sup>6b</sup>

<sup>a</sup>Mechanical & Industrial Engineering Technology, University of Johannesburg, South Africa

<sup>b</sup>Mechanical Engineering Science, University of Johannesburg, South Africa

<sup>c</sup>Department of Mechanical Engineering, Covenant University, Ota, Nigeria

E-mail: <sup>1</sup>[stephenakinlabi@gmail.com](mailto:stephenakinlabi@gmail.com); <sup>2</sup>[mmashinini@uj.ac.za](mailto:mmashinini@uj.ac.za);

<sup>3</sup>[Oluseyi.ajayi@covenantuniversity.edu.ng](mailto:Oluseyi.ajayi@covenantuniversity.edu.ng);

<sup>4</sup>[Abiodun.abioye1@covenantuniversity.edu.ng](mailto:Abiodun.abioye1@covenantuniversity.edu.ng); <sup>5</sup>[drfatobasameni@gmail.com](mailto:drfatobasameni@gmail.com);

<sup>6</sup>[etakinlabi@gmail.com](mailto:etakinlabi@gmail.com)

**Abstract.** Laser Metal Deposition (LMD) is a unique way of building components by adding the material(s) layer by layer until the components are built. This process is based on the geometry path defined by the CAD model data from the component development. This paper reports on the characterization of Laser Metal Deposited Titanium alloy and Molybdenum Powder on Titanium alloy grade 5 substrate. The depositions are the process of delivering of the Titanium and Molybdenum powder from a powder feeder of two different hoppers containing each powder. The deposited samples were achieved through the combination of different ratios of Titanium and Molybdenum, i.e. 95%, 90% and 85% of Titanium and 5%, 10%, 15% Mo respectively. Three sets of experiments were conducted with multiple tracks at a constant laser power of 1.2kW, Scan speed of 0.5m/min and gas flow rate at 2 l/min. While the powder flow rate for both Ti6Al4V and Mo were varied. The deposits were sectioned through the thickness, metallographically prepared and characterized through microstructural evaluation and microhardness. The results from the microstructure revealed that columnar grains describe the layers, which gives an excellent interfacial bonding between the layers. The Micro Vickers hardness values were observed to decrease as the percentage of Mo increases. Through the EDS, the un-melted powders and pores were identified. Also, the grain sizes were found to reduce as the percentage of Molybdenum increases.

## 1. Introduction and Background

Laser Metal Deposition (LMD) is one of the Additive Manufacturing (AM) processes whereby new components can be produced and old components refurbished. LMD process remains very unique as a process that can achieve both the manufacture of a new component and the repair of old component part. It's an alternative manufacturing technique for special materials such as Titanium and its alloys that has found relevance in aerospace, medical, automotive, chemical and oil & gas applications. LMD employs a layer-by-layer process of manufacturing lightweight components part, with unique properties from the 3D CAD data. A typical schematic of an LMD process is illustrated with Figure 1. The manufacturing process employs the heat source from the laser beam and deposited powder through a feeder nozzle onto a substrate where the component part is built layer by layer.



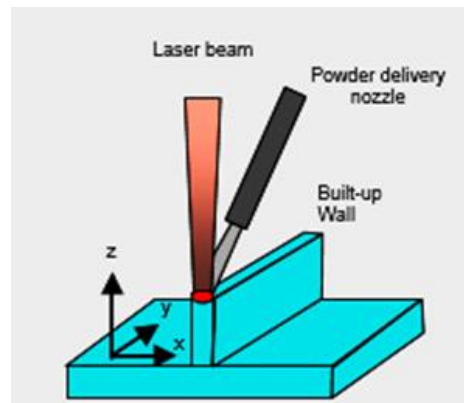


Fig. 1 Schematic of Laser Metal Deposition Process [1]

The LMD process has proven to be a unique alternative manufacturing process when compared to conventional manufacturing processes in which materials are always removed from the substrate which consequently lead to material wastages, high machine hour, high energy consumption and possible pollution to the environment. The use of conventional manufacturing process in the production of aerospace components parts has been associated with material wastages, making the process not sustainable because only about 10% of the input material eventually comes out as the final manufactured component. This is commonly referred to as the high buy-to-fly ratio in the aerospace industry, which has been attributed as one of the reasons for the high cost of aircraft [2]-[5]. On the other hand, LMD has the capability reducing the setup time, which consequently reduces the production cost, material wastages, energy consumption and man hour time.

Functionally Graded Material (FGM) is a special material developed with unique properties tailored for particular applications such as in aerospace, medical, automotive, energy and military etc. [6]-[7]. FGM has been developed to eliminate the point of stress initiation and concentration in a joining process of the manufactured component, which often acts as a point of reference and initiation for failure. These points are sharp interfaces observed in the joined material, which FGM has successfully eliminated through the developed material gradient in an LMD process [8]-[9]. Historically, FGM has been produced from different production processes such as Powder Metallurgy Approach, Centrifugal Casting Technique, Plasma Spraying Method, Self-propagating High-Temperature Synthesis, Physical or Chemical Vapour Deposition (PVD/CVD) and recently the Laser Metal Deposition Process [10]-[11].

Several studies into LMD process has been investigated, and some of the successes are now applied to the refurbishment and repairs of cracked components such as turbine blades [12]-[16]. More particularly, research into FGM of Titanium and its alloy has also gained good ground [7], [17]-[21]. Zhang et al. contributed to the development of FGM using LMD process and further characterized the graded material [22]. They deposited functionally graded Ti-TiC on a Ti6Al4V substrate. Through the preliminary study, the processing parameters for various volume fractions of Ti-TiC composites were established. The results were then used to deposit thin wall of FGM by optimizing the process parameters during the process. The study revealed that the wear resistance of the Ti6Al4V substrate was improved by the addition of the TiC and show the produced FGM without sharp interfaces. Wang et al. [23] conducted another similar study of functionally graded Ti6Al4V-TiC deposit. In this study, Ti6Al4V wire and TiC powder were used, with the two materials fed simultaneously. An excellent compositional graded material was achieved with the wire feed rate of Ti6Al4V constant and varying the feed rate for TiC. Liu and DuPont [24] employed the controller in LENS to monitor the melt pool area of the deposited FGM of Ti-TiC composite using LMD. The controller in LENS was also used to regulate the laser power to achieve a constant melt pool area during the deposition. The control of the

melt pool area is intended to control the dimensional accuracy in the deposited part while other properties of the deposit are not affected. The study of functionally graded Inconel 718 Nickel alloy and Ti6Al4V using laser metal deposition was conducted by Shah [25]. He investigated the effect of pulse parameters and powder flow rate on residual stress. The results revealed that the thickness of the layer has a contributory role in the crack formation in the deposit. It was also noted that increase in the powder flow rate increases the melt pool size. The solidification behaviour and microstructure of the functionally graded material of stainless steel-SS316L-super alloy-Rene88DT were studied through the laser metal deposition. The results show the development of Epitaxial growth and columnar dendrites microstructure [26].

The focus of this research is to incorporate varying percentages of Molybdenum on Titanium alloy through LMD, for biomedical application such as in knee and hip implant. Functionally graded Ti6Al4V- Molybdenum was developed through the laser metal deposition process. The process parameters employed for the deposition layer by layer as from the initial preliminary study, which was optimized to establish the process window for the deposition of porous free and dense deposit of Ti6Al4V-Mo composites. Molybdenum has been having been chosen because of its biocompatibility while Titanium alloy grade 5 is the most valuable among the grades of Titanium alloys.

The parameters considered in this study are Laser Power, Scan Speed, Powder Flow Rate, Gas Flow Rate and Percentage of Molybdenum. The produced deposited samples were characterized by mechanical, Microhardness and microstructural analysis using SEM microscopy.

## 2. Experimental Methods

The substrate employed in the laser metal deposition of the functionally graded Ti6Al4V-Mo composite is 5 mm Ti6Al4V, with a dimension of 72x72mm<sup>2</sup>. The Ti6Al4V samples were sandblasted to remove all oxide layers and dirt. It's cleaned with acetone before the deposition commences. In addition, the sandblasting is aimed to make the surface rough to aid laser power-material interaction and eliminate reflection of shining surfaces that may reflect the laser beam. The Ti6Al4V and Mo powder were used in the deposition of the functionally graded composites. The particle size of the Ti6Al4V powder is 150-300  $\mu\text{m}$  and has 99.6% purity. While the particle size of the Mo powder is 45-120  $\mu\text{m}$  and with a purity of 99.6%. The morphology of the parent materials – substrate, Ti6Al4V and Mo are shown in Figure 2 (a), (b) and (c) respectively.

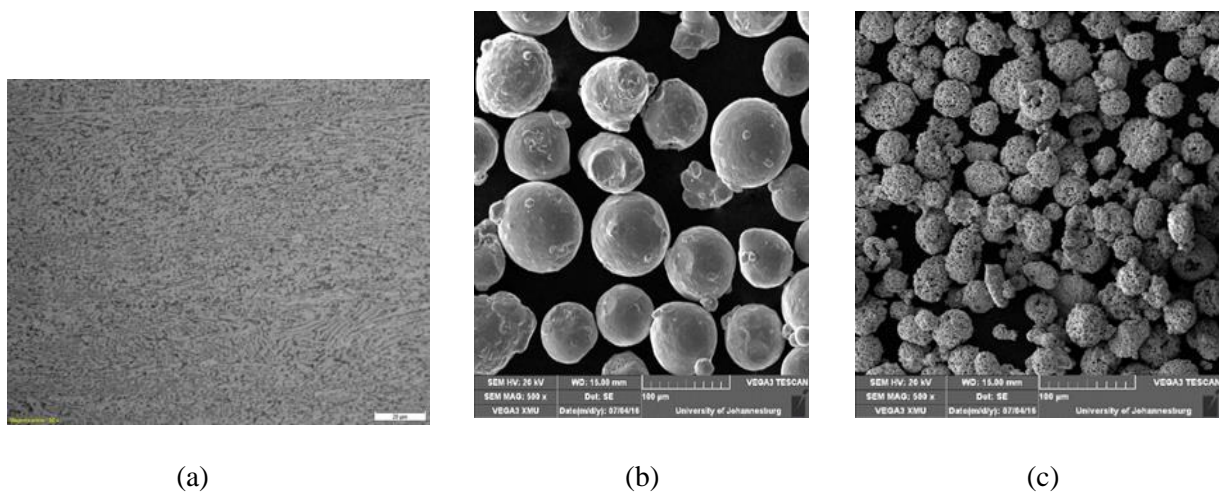


Fig. 2 Characterization of parent materials showing the morphology of (a) Ti6Al4V substrate (b) Ti6Al4V powder (c) Mo Powder

During the LMD process, a 4.4kW ND: YAG laser system was employed, attached to a KUKA robot. A co-axial nozzle was equipped with the robot for the effective delivery of the powder to the melted pool. Both the Ti6Al4V and Mo powders are transported with the aid of Argon gas through the nozzle and also to protect the deposit from contamination from the environment. The beam spot size was kept at 2mm at a focal length of 195 mm above the Ti6Al4V substrate. The experimental setup and schematic of the LMD process are shown in Figure 3 (a) and (b) respectively.

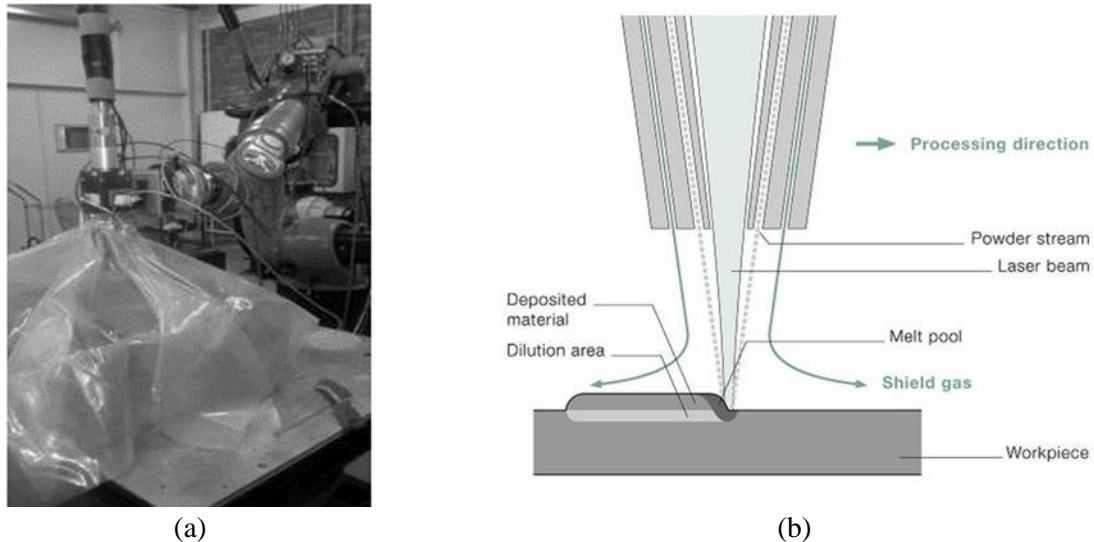


Fig. 3 (a) Experimental setup and (b) Schematic of the Laser Metal Deposition

The LMD was achieved through the developed melted tool on the surface of the Ti6Al4V substrate using the laser beam. The powders were emptied into the melted pool through the powder feeders. The Ti6Al4V substrate was positioned stationary while the robot was engaged in the deposition as depicted in the schematic shown in Figure 3 (b). The functionally graded material was produced from different percentages of both Ti6Al4V and Mo, the process parameters presented in Table 1.

Table 1 Process Parameters.

Sample #	% Ti6Al4V	% Mo	P (KW)	V (m/min)	Powder flow rate (rpm)		Gas flow Rate (l/min)
					Ti6Al4V	Mo	
1	95	5	1.2	0.5	3.8	0.2	2
2	90	10	1.2	0.5	3.6	0.4	2
3	85	15	1.2	0.5	3.4	0.6	2

The deposited samples were after that characterized to determine the integrity of the deposited samples. The deposited samples selected for metallurgical examinations were sectioned to reveal the cross-sections. The cut samples were mounted in hot resin - polyfast and the mounted samples were ground and polished based on the metallurgical preparation standard for Titanium and its alloys. The polished samples were etched using Kroll's reagent. The microstructures were observed under an optical microscope and also through the Scanning Electron Microscope (SEM) with a capacity to conduct Energy Dispersion Spectrometry (EDS). The hardness of the deposited samples was also evaluated through microhardness profiling of the cross-section of the polished samples using the Vickers Microhardness indenter. A load of 500 g and dwell time of 15 sec was applied.

### 3. Result and Discussion

The micrographs of the Ti6Al4V substrate and the powders are shown in Figure 2 (a), (b) & (c). White and grey colourations, which are the alpha grains and Beta grains, were observed to be distributed across the whole cross-section of the micrograph. The Ti6Al4V powder is spherical; this is typical of a gas-atomized powder. The spherically shaped powder is always encouraged for laser metal deposition process because these maximize the absorption of the laser beam. The shapes of the Molybdenum powder, on the other hand, are irregular and rough; these shape characteristics are often typical of ball milled powder.

A sample photo of the Functionally Graded Ti6Al4V & Mo is shown in Figure 3 with multiple track depositions.

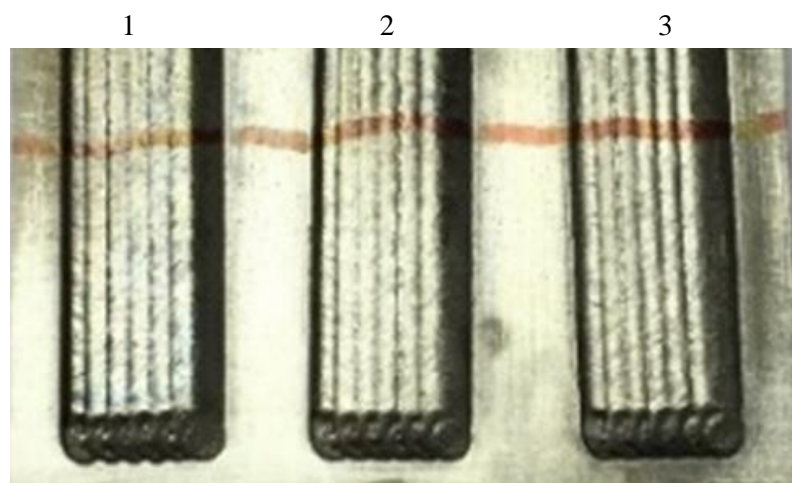


Fig. 4 Physical photo of Laser Melted Deposition at 5%, 10% and 15% of & Mo on the Ti6Al4V substrate

The microhardness test was conducted on the three deposited samples, and the average microhardness was presented in Table 2. The trend observed in Table 2 revealed that as the percentages of Molybdenum increases, the average microhardness decreases. This phenomenon is attributed to the Vickers hardness for Ti6Al4V and Molybdenum are 349 and 230 HV respectively. The minimum percentage of Mo has little influence on the deposited composite, having Ti6Al4V dominate and similarly, the increased portion of Mo had a more significant impact on the formed composite, which consequently reduced the microhardness.

Table 2 Average grain sizes of deposited samples at percentages of Mo.

% Mo	Average Grain Size ( $\mu\text{m}$ )
5	451.6632
10	279.7058
15	139.0304

The micrographs of the depositions of Molybdenum at 5%, 10% and 15% and 95%, 90% and 85% Ti6Al4V powder on Ti6Al4V substrate is shown in Figure 5. All the micrographs distinctively show the deposit the HAZ, HAZ and substrate. Also observed across the three deposits are porosity and un-melted Molybdenum powders, which may be attributed to the constant laser power employed in the deposition



process. The grains for the deposit with 10% molybdenum are elongated, which is different from the other deposits. This may be attributed to the cooling rate during the deposition process. The deposit produced with 15% of Mo reveal that the laser beam deployed to the process is low because this has resulted in un-melted Molybdenum. It would be expected that the laser power is increased for the effective melting of both the powder and formation of the melted pool.

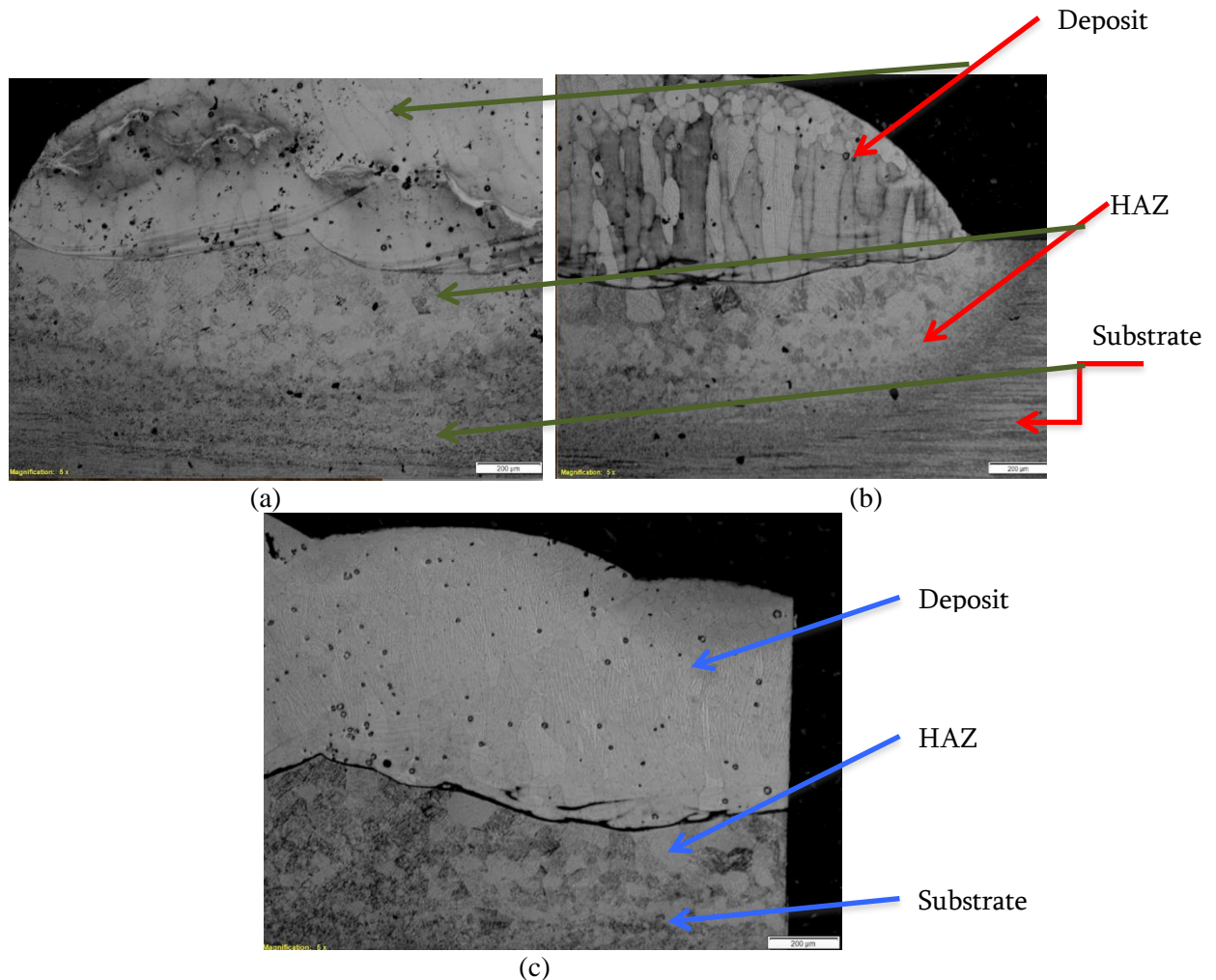


Fig. 5 Deposition at (a) 5% Mo, (b) 10% Mo and (c) 15% Mo

A typical SEM micrograph of the deposited sample with un-melted Molybdenum powder is shown in Figure 6 (a). The un-melted Molybdenum particles are confirmed through the EDS analysis of the selected point in (a).

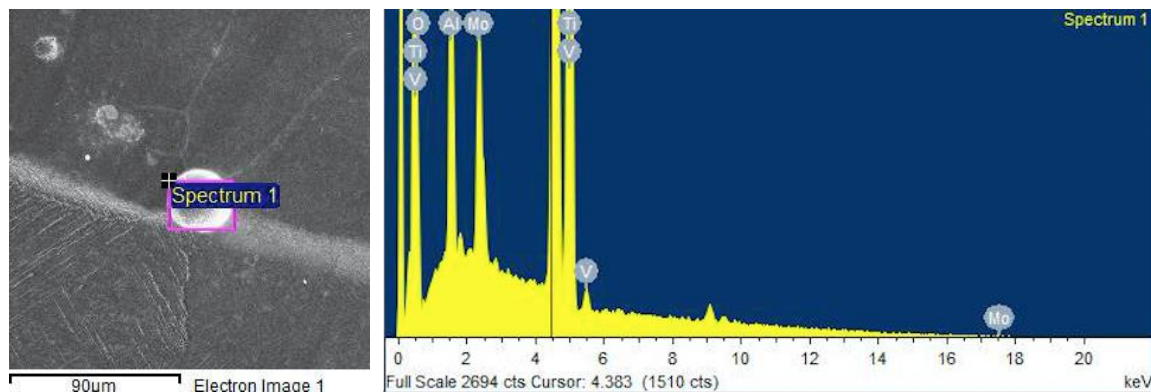


Fig. 6 (a) SEM Microstructure of a deposited sample (b) The EDS analysis of the labeled point in (a)

#### 4. Conclusion

Through this study, Ti6Al4V-Mo Composites were successfully produced with the three sets of powder compositions at varying powder flow rates and constant laser power, scan speed and gas flow rates. The Vickers Microhardness values were found to be a function of the percentage composition of Molybdenum powder. The deposit produced at 10% Molybdenum show good bonding with the substrate and deformed columnar grains, which have been attributed to the adequate bonding between the deposit and the substrate. In addition, the columnar grains and the pores also provide good ose-integration of the body tissue when inserted into simulated body fluid.

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