Gas Flow Rate and Powder Flow Rate Effect on Properties of Laser Metal Deposited Ti6Al4V

Sisa Pityana, Rasheedat M. Mahamood*, Esther T. Akinlabi, and Mukul Shukla

Abstract— Tracks of Ti6Al4V powder were deposited on Ti6Al4V substrate using Laser Metal Deposition (LMD) process, an Additive Manufacturing (AM) manufacturing technology, at a laser power and scanning speed maintained at 1.8 kW and 0.005 m/s respectively. The powder flow rate and the gas flow rate were varied to study their effect on the physical, metallurgical and mechanical properties of the deposits. The physical properties studied are: the track width, the track height and the deposit weight. The mechanical property studied is the Microhardness profiling using Microhardness indenter at a load of 500g and dwelling time of 15 µm. The metallurgical property studied is the microstructure using the Optical microscopy. This study revealed that as the powder flow rate was increased, the track width, track height and the deposit weight were increased while as the powder flow rate was increased, the track width, track height and the deposit weight decreased. The results are presented and discussed in detail.

Keywords— Gas flow rate, Laser Metal Deposition (LMD), Microhardness, Microstructure, Powder flow rate.

I. INTRODUCTION

Laser Metal Deposition (LMD) is an Additive Manufacturing (AM) technology that belongs to the Energy Deposition class as was recently grouped by the F42 committee on AM standards [1]. LMD like any AM process produces 3 dimensional (3D) components directly from CAD model of the component in one step [2,3]. During the laser metal deposition process, powder is fed into the melt pool created by laser on the substrate, which upon solidification forms the contour defined by the CAD data information of the component. Apart from making new product directly from CAD file, LMD process can be used to repair worn out components [4,5]. LMD has the capability to handle more than one material simultaneously, hence it can be used to produce functionally graded part [6]. LMD can also reduce buy-to-fly ratio for aerospace parts [7]. Processing parameters has great influence on the properties of laser metal deposited parts as was shown in the literature [8-10]. Effect of gas and powder flow rates effect on property is scarce in the literature.

The most commonly used and produced titanium alloy is Ti6Al4V [11] because it possesses excellent structural and corrosion resistance properties [12]. Titanium is generally classified as difficult to machine material because of the high interaction between the titanium and the cutting tool materials [13]. With all the difficulties presented in machining titanium through traditional manufacturing processes, AM, a tool-less process provide the best alternative manufacturing technique for processing titanium and its alloys.

Against this background, this paper studies the effect of powder flow rate and gas flow rate on the physical (height, width and weight of the deposit), metallurgical (microstructure) and mechanical (Microhardness) properties of Ti6Al4V parts produced using laser metal deposition process. The results obtained are presented and fully discussed.

II. EXPERIMENTAL PROCEDURE

The schematic of the LMD process as achieved in this study to produce the samples is shown in Figure 1.

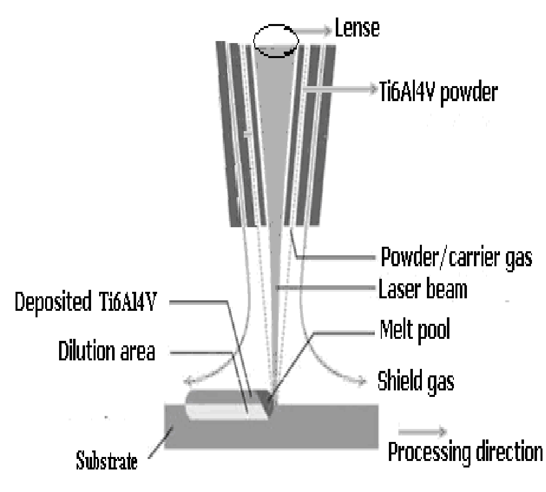


Figure 1. Schematic of the Laser Material Deposition

Manuscript received December 9, 2012; revised January 8, 2013. This work was supported by the Rental Pool Grant of the National Laser Centre -Council of Scientific and Industrial Research (NLC-CSIR), Pretoria, South Africa and The Schlumberger Foundation Faculty for the Future (FFTF).

Prof Sisa Pityana is a Research Scientist in the National Laser Centre of Council for Scientific and Industrial Research (CSIR), Pretoria, South Africa. (E-mail: SPityana@csir.co.za.)

* Ms. Rasheedat M. Mahamood is a doctorate Student in the Department of Mechanical Engineering Science, University of Johannesburg, Auckland Park Campus, Johannesburg, South Africa, 2006. (e-mail: mahamoodmr@unilorin.edu.ng or mahamoodmr@yahoo.com)

Dr Esther T. Akinlabi is a Senior Lecturer in the Department of Mechanical Engineering Science, University of Johannesburg, Auckland Park Campus, Johannesburg, South Africa, 2006. (Phone: +2711-559-2137; email: etakinlabi@uj.ac.za).

Prof Mukul Shukla is an Associate Professor in the Department of Mechanical Engineering Science, University of Johannesburg, Auckland Park Campus, Johannesburg, South Africa, 2006. (e-mail: mshukla@uj.ac.za).

The powder was placed in a hopper and released in a controlled manner as required. A 4.4 kW Nd-YAG Rofin Sinar fiber laser was used in this study and the deposition process was controlled by a Kuka robot which carried the laser and the powder delivery nozzles in its end effector. The laser power and the scanning speed were maintained at 1.8 kW and 0.005 m/s respectively through out the deposition process while the powder flow rate and the gas flow rates were varied to study their effects on property of the deposited part. A single track each of length 60mmm was deposited at each processing parameter shown if Table 1.

Table 1. Processing parameters

Sample Designat ion	Laser Power (kW)	Scanning Speed (m/Sec)	Powder Flow Rate (g/min)	Gas Flow Rate (l/min)
A	0.8	0.005	2.88	4
B	1.8	0.005	2.88	2
C	1.8	0.005	5.76	2
D	1.8	0.005	5.76	4

The laser sport size was maintained at approximately 2mm above the substrate at a focal length of 195mm. the deposition was conducted in a protected atmosphere (glove box filled with argon gas) keeping the oxygen level below 10 PPM

A hot rolled 99.6% pure Ti6Al4V 72 X 72 X 5 mm thick plate was used as substrate and Ti6Al4V powder of the same purity and of particle size range between 150 and 200 µm. The substrate was sandblasted and degreased with acetone before deposition process to improve laser power absorption and to improve metallurgical bonding of the melted powder and the substrate.

After the deposition process, the samples were laterally sectioned, ground and polished and etched according to the standard metallographic preparation of Titanium. Olympus optical microscope (Olympus BX51M) was used to study the microstructure of the samples. Stereo microscopy was also used to study the physical appearance of the deposits. After each deposition, the substrate is cleaned and wire brushed to remove the unmelted powder particle that clings on the surface of the substrate. A chemical balance was used to measure the weight of the substrate before and after deposition.

The Microhardness profiling were carried out using MH-3 Vickers hardness indenter developed by Metkon with a load of 500g, a dwell time of 15 seconds and the space in between indentations of 15µm.

III. Results and discussion

3.1 Results

Table 2 shows the processing parameters and the measured track width, track height and deposition weight corresponding to each set of processing parameters. The micrograph of the substrate is shown in Figure 2. Figure 3a. shows the micrograph of the Ti6Al4V powder and the particle size distribution is shown in Figure 3b. The macrograph of the samples with and height measurement are shown in Figure 4 (a) and (b). The microstructure of the samples at powder flow rate of 2.88 g/min and gas flow rate of 2 l/min is shown in Figure 5a

Table 2. Table of result for track height, track width, and Deposition weight

Sampl e Desig nation	Powder Flow Rate (g/min)	Gas Flow Rate (l/min)	Track Width (mm)	Track Height (mm)	Depo sit Weig ht (g)
A	2.88	4	2.22	0.3	0.04
B	2.88	2	2.16	0.14	0.03
C	5.76	2	2.04	0.08	0.02
D	5.76	4	2.14	0.24	0.03

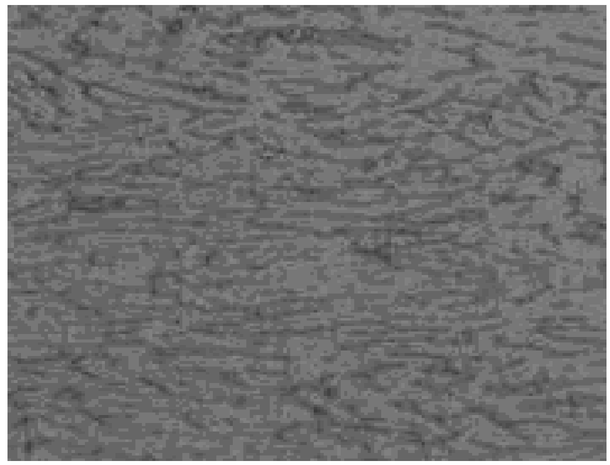
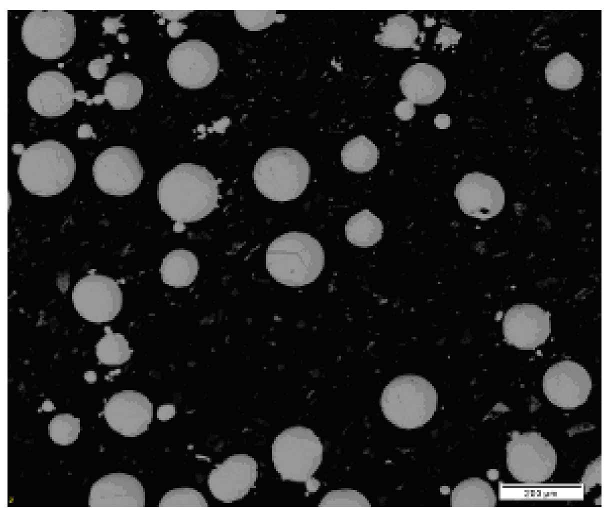
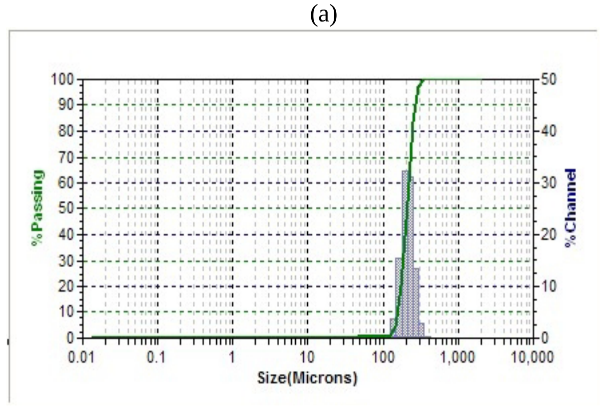


Figure 2: Micrograph of the substrate



(a)

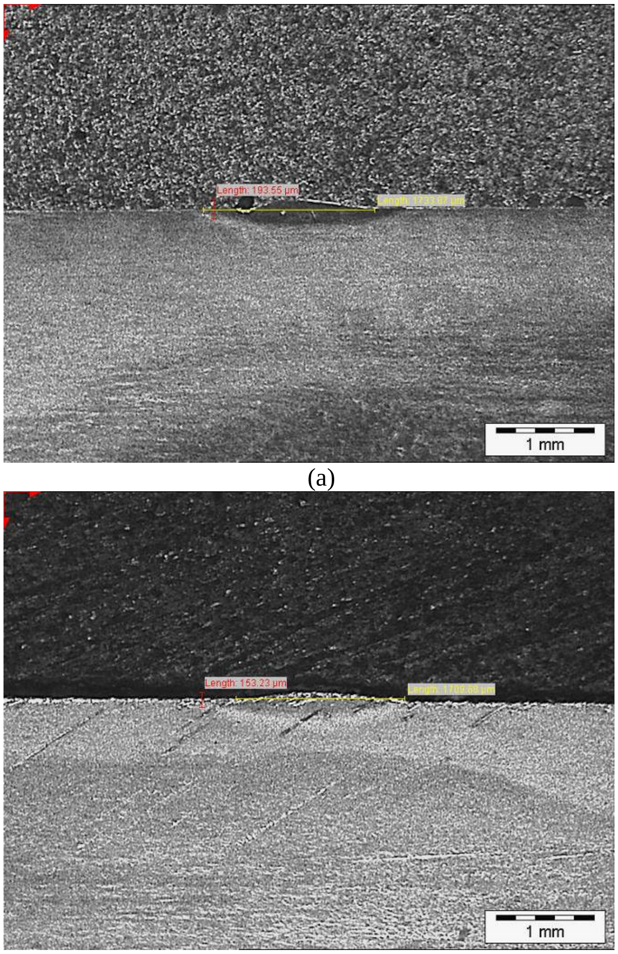


(b)

Figure 3: (a) Micrograph of the Ti6Al4V powder, (b) The Particle size analysis of the Ti6Al4V powder

ISBN: 978-988-19252-6-8
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

while the micrograph of the sample at powder flow rate of 5.76 g/min and the gas flow rate of 4 l/min is shown in Figure 5b.



(a)

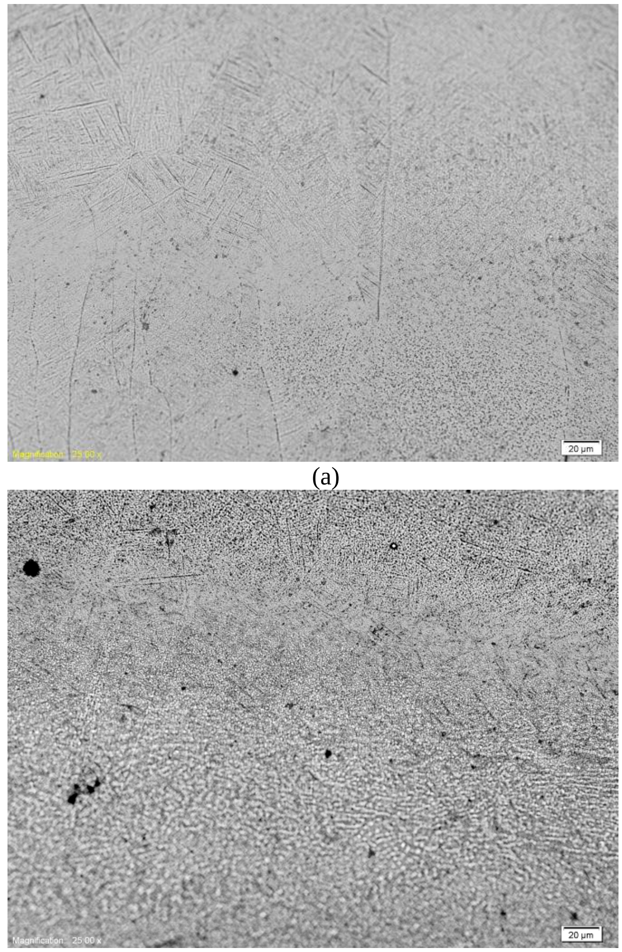
(b)

Figure 4: Macrograph of sample at powder flow rate and gas flow rate of (a) 5.76 g/min and 2 l/min (b) 5.76 g/min and 4 l/min

3.2 Discussion of Results

The micrograph of the substrate observed under the optical microscope reveals a lamellar structure of alpha and beta phases. The beta phase (dark parts) is finely dispersed in the matrix of alpha (lighter parts) phases. The micrograph of the Ti6Al4V powder shown in Figure 3a consists of spherical shaped gas atomized. The particle size distribution (see Figure 3b) is Gaussian distribution.

Table 2 shows an increase in track width, track height and deposition weight of the samples as the power flow rate is increased. The macrographs with these measurements for samples A and D are shown in Figures 4(a) and (d). The reason for the increase in the width, height and deposition weight can be attributed to the fact that, as the powder flow rate is increase, more powder is delivered and fed into the melt pool. The microstructures of the sample at a powder flow rate of 2.88g/min which is the minimum powder flow rate considered in this study (see Figure 5a) is characterized by coarse alpha lath as a result of longer time taken by the melt pool to solidify. Comparing Figure 5a and 5b (sample



(a)

(b)

Figure 5: Microstructure of the deposit zone of sample at powder flow rate and gas flow rate of (a) 2.88 g/min and 2 l/min (b) 5.76 g/min and 4 l/min.

The bar chats of the average Microhardness of all the samples and that of the substrate is shown in Figure 6.

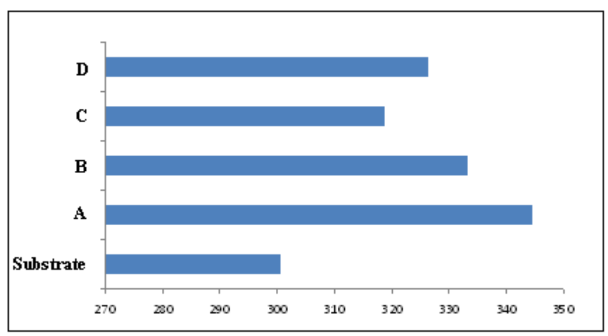


Figure 6: The bar chat of the average microhardness of samples A to D and the substrate.

at maximum powder flow rate of 5.76 g/min) reveal that as the powder flow rate is increased the alpha lath becomes finer. This shows that the powder flow rate should not be indefinitely increased because a point will be reached when the available energy density (which is a function of laser power and the scanning speed) will not be enough to completely melt the delivered powder; this phenomenon has been established in the previous work [8] Also from the

ISBN: 978-988-19252-6-8
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

Table 2. it was observed that, as the gas flow rate is increased the track width, the track height and the deposition weight are decreasing .The reason for this type of Behaviour can be attributed to an increase in disturbance on the powder flow pattern as the gas flow rate is increase causing less powder to be actually delivered into the melt pool and most of the powder are blown away from the melt pool.

The average Microhardness value of each of the sample as compared to that of the substrate (see figure 6) is found to be highest in the sample at the powder flow rate of 5.76g/min and gas flow rate of 2L/mim. This further confirms that at low gas rate more powder is delivered in to the melt pool because there are fewer disturbances in the powder flow path.

IV CONCLUSSION

Ti6Al4V powder has been deposited on Ti6Al4V substrate. The powder flow rate was varied between 2.88 g/min and 5.76 g/min, the gas flow rate was also varied between 2 and 4 l/min, while the laser power and the scanning speed were kept constant at 1.8 kW and 0.005 m/s respectively. The study on the effect of changing powder flow rate and gas flow rate reveal that as the gas flow rate is increased, the track width, the track height ant the deposit weight is reduces due to higher disturbance in powder flow path created by high gas flow rate. For the parameter considered in this study, the track width, the track height ant the deposit weight is found to increase as the powder flow rate is increased. The average Microhardness decreases with an increase in the gas flow rate and increases as the powder flow rate is increased.

Acknowledgments

This work is supported by the Rental Pool Grant of the National Laser Centre - Council of Scientific and Industrial Research (NLC-CSIR), Pretoria South Africa and The Schlumberger Foundation Faculty for the Future (FFTF).

REFERENCES

[1] J. Scott, N. Gupta, C. Wember, S. Newsom, T.Wohlers and T. Caffrey, Additive Manufacturing: Status and Opportunity, Science and Technology Policy Institute, 2012.

[2] G.K. Lewis and E. Schlienger, (2000), Practical considerations and capabilities for laser assisted direct metal deposition, Materials and Design, vol. 21, pp. 417-423.

[3] J. Mazumder and L. Song, (2010), Advances in Direct Metal Deposition, A laser workshop on Laser Based Manufacturing, University of Michigan, available at http://www.seas.virginia.edu /research/lam/pdfs/speaker %20presentations/Mazumder-NSF-IUCRC%20workshop-2010. Pdf, Aaccessed online on 26th August 2011.

[4] A. J. Pinkerton, W. Wang, and L. Li, (2008), Component repair using laser direct metal deposition, Proc. IMechE Part B: J. Engineering Manufacture, 222, 827-836.

[5] R. Cottam, and M. Brandt, (2011). Laser cladding of ti-6al-4v powder on ti-6al-4v substrate: Effect of laser cladding parameters on microstructure, *Physics Procedia*, 12, 323–329.

[6] R. M. Mahamood, E. T. Akinlabi, M. Shukla and S. Pityana, (2012). Functionally Graded Material: An overview, *Lecture Note in Engineering*, WCE 2012, July 4-6,2012, London, United Kingdom, 3, 1593-1597.

[7] E. Brandl, V. Michailov, B. Viehweger, C. Leyens, (2011). Deposition of Ti–6Al–4V using laser and wire, part I: Microstructural properties of single beads, *Surface & Coatings Technology*, 206, 1120–1129.

[8] R.t M. Mahamood, E. T. Akinlabi, M. S. and Sisa Pityana (2012), Effect of Laser Power on Material Efficiency, Layer Height and Width of Laser Metal Deposited Ti6Al4V, World Congress of Engineering and Computer Science (WCECS), San Francisco 2012, 24-26 October 2012, vol. 2, pp. 1433-1435.

[9] Esther T. Akinlabi, Rasheedat M. Mahamood, Mukul Shukla and Sisa Pityana (2012), Effect of Scanning Speed on Material Efficiency of Laser Metal Deposited Ti6Al4V, Accepted for oral presentation at the World Academy of Science, Engineering and Technology (WASET 2012), 28-28 November 2012.

[10] R. M. Mahamood, E. T. Akinlabi, M. Shukla and S.Pityana (2012), Laser Metal Deposition of Ti6Al4V: A Study on the Effect of Laser Power on Microstructure and Microhardness, Accepted for oral presentation at the 2013 International Multiconference of Engineering and Computer Science (IMECS 2013), March 2013.

[11] M. Peters, J. Kumpfert, C.H. Ward, C. Leyens, (2003). Titanium alloys for aerospace applications, in : Titanium and Titanium alloys, *Advanced Engineering Materials*, 5, 419- 427.

[12] Y., Lu, H.B. Tang, Y.L. Fang, D. Liu, and H.M. Wang, (2012). Microstructure evolution of sub-critical annealed laser deposited Ti–6Al–4V alloy, *Materials and Design*, 37, 56–63.

[13] Z.M, Wang and E.O. Ezugwu, (1997). Titanium Alloys and Their Machinability a Review. *Journal of Material Processing Technology*, 68, 262-270.