Effect of Scanning Speed on Material Efficiency of Laser Metal Deposited Ti6Al4V

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

***Abstract*—**The study of effect of laser scanning speed on material efficiency in Ti6Al4V application is very important because unspent powder is not reusable because of high temperature oxygen pick-up and contamination. This study carried out an extensive study on the effect of scanning speed on material efficiency by varying the speed between 0.01 to 0.1m/sec. The samples are wire brushed and cleaned with acetone after each deposition to remove un-melted particles from the surface of the deposit. The substrate is weighed before and after deposition. A formula was developed to calculate the material efficiency and the scanning speed was compared with the powder efficiency obtained. The results are presented and discussed. The study revealed that the optimum scanning speed exists for this study at 0.01m/sec, above and below which the powder efficiency will drop.

***Keywords*—**Additive Manufacturing, Laser Metal Deposition Process, Material efficiency, Processing Parameter, Titanium alloy.

I. Introduction

TITANIUM alloy is an important aerospace material because of its exiting properties that include: high specific strength, stiffness, toughness and low coefficient of thermal expansion [1]. Despite all these exciting properties there are serious challenges in processing this material using traditional fabrication methods [2], some of these challenges include galling of the cutting tool and generation of high temperatures at cutting tool edge [2] that is why there is need for alternative manufacturing technique. Laser Metal Deposition (LMD), an Additive Manufacturing (AM) technique is the right candidate technique for processing titanium and its alloy because it offset most of the problems of the traditional manufacturing methods [3], since AM is a tool-less process. Also AM technology is a promising aerospace manufacturing technique [4] as it has the potential of reducing the buy to fly ratio [5] and it's useful for repair of high valued parts [6]. Material efficiency is always very high in AM technology as unspent materials can still be reused with some materials. This is not possible with titanium because it is highly susceptible to oxygen pick-up at high temperature [7]; unspent titanium alloy powder would have been contaminated with oxygen which may not be reusable for the intended application [8]. To really take full advantage of AM technology there is need to fully understand the effect processing parameters have on material efficiency and the overall economy of the system. There is need to study the effect of processing parameter on the efficiency of material when it comes to titanium and its alloy because of the contamination of the unspent titanium powder and also because titanium powder is very expensive.

In this study laser metal deposition (LMD) process (an additive manufacturing technique) was used for series of deposit using Ti6Al4V powder. The most important process parameters in LMD are laser power, scanning speed, powder flow rate and gas flow rate [9]. The laser power, powder flow rate and gas flow rate were maintained at 3kW, 5.64g/min and 4l/min respectively. The scanning speed was varied from 0.01m/sec to 0.1m/sec and 0.005m/sec. Effect of scanning speed on material efficiency was extensively studied. The rest of the paper is organized as follows: section II gives the experimental method; results and discussion are presented in section III, while section IV gives the concluding remarks and future work plan.

II. Experimental Procedure

Experimental procedure is subdivided into three namely: the deposition process, macro and microstructural exterminations and material efficiency determination.

A. Laser Metal Deposition Process

A commonly used aerospace alloy Ti–6Al–4V was used in this study. 99.6% pure 72x72x5mm Ti–6Al–4V substrate was used. Ti–6Al–4V powder of particle size of 150-200μm was also used. The LMD system established in this study consists of a Kuka robot, Nd-YaG 4.4kW laser which is used to melt Ti64Al4V powder that is delivered by argon gas through coaxial nozzles, a powder feeder with two hoppers and a box for oxidation protection during deposition were used (see Fig. 1. for the experimental set up). The schematic of the deposition process is shown in Fig. 2. The focusing point maintained at 195 mm above the substrate gives a laser spot size on the substrate of approximately 2mm. The substrate

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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).

surface was sand blasted and cleaned with acetone before deposition.

To study the effect of processing parameter on material efficiency, only scanning speed was varied in this study. The reason for the choice of varying only the scanning speed is that it will be easy to implement close loop control on the system by just controlling the scanning speed. The scanning speed was varied between 0.01 and 0.1m/sec, also the effect at 0.005m/sec is further studied to give better understanding of the trend in the lower scan speed direction. The laser power, powder flow rate and gas flow rate were kept constant at 3kW, 5.64g/min and 4l/min respectively.

Fig. 1 Experimental Set-up

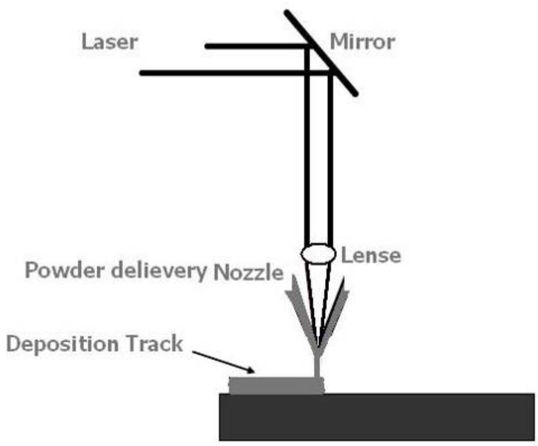

Fig. 2 Schematic of Laser Metal Deposition

B. Macrostructure and Microstructure Examination

The deposited tracks were laterally sectioned and metallographically prepared and etched with 2% Kroll reagent for macroscopic and microscopic observation. Samples are studied under optical microscope at 40x magnification for macrographic extermination in terms of dimension of the deposited track. Higher magnification was used for microstructural examination to study the metallurgical integrity of the deposits.

C. Material Efficiency Determination

To study powder efficiency, there is need to determine the weight of powder used in the deposition process. The deposit is wire brush cleaned and washed in acetone to remove clinked powder particles. The substrate is weighed before and after deposition, change in weight gives the weight of the powder deposited.

$$m_D = m_{SD} - m_S \qquad (1)$$

Where: m_D is mass of powder deposited, m_S is mass of the substrate before deposition process and m_{SD} is the mass of substrate after deposition. To determine the mass of powder delivered by the powder feeder. We need to first determine the time taking for the deposition (T_D). A single track of length L, 60mm, was deposited each. The scanning speed (S_S) is

$$S_S = L/T_D \quad \text{and} \quad T_D = L/S_S \qquad (2)$$

Mass of powder delivered (m_P) during deposition is

$$m_P = \left(P_{FR} \times T_D\right) \div 60 \qquad (3)$$

P_{FR} is the powder flow rate. The powder efficiency (μ) is

$$\mu = \left(m_D / m_P\right) \times 100 \qquad (4)$$

III. Results and Discussion

The micrograph of the substrate and the morphology of the powder used in this study are shown in Fig. 3. Figs. 4 and 5 show the macrographs and the micrographs of samples 1 to 10 at processing parameter shown in Table I. The macrographs shows the deposited track at each processing parameter and the micrographs shows the metallurgical integrity of the tracks. The micrographs are taken at the interface of the deposited layer and the substrate. It is can be seen that there is no porosity in all the deposits so they all bonded well to the substrate. Equations (1) to (4) are used to calculate deposited time and finally the material efficiency of samples 1 to 10 obtained from the processing parameters. The details of this are given in Table I.

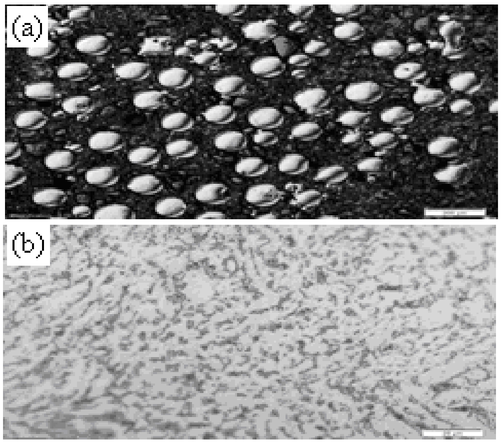

Fig. 3 (a) The Morphology of Ti6Al4V powder (b) Micrograph of the substrate

the longest dwelling time, this leads to more unmelted powder and hence lowest powder efficiency.

IV. Concussion and Future Work

Laser metal deposition process is of great importance to the aerospace industry because of its unique property of making parts directly from CAD data as well as repair of high valued parts. Generally, materials used with this process are reusable as unspent powders can be reused for other applications. The story is different for Ti6Al4V, an important aerospace allow because of its susceptibility to oxygen pick up at high temperature. Hence there is need to find the right processing parameter that will maximize the use of this expensive material for the overall economy of the system. In this study, effect of scanning speed on material efficiency was studied leaving other processing parameters namely: laser power, powder flow rate and gas flow rate constant. The study has revealed that with the set of processing parameter considered an optimum scanning speed of 0.01m/sec was obtained with

TABLE I
Results Showing Track Heights, Widths and Material Efficiency

Sample No.	LASER POWER (kW)	SCANNING SPEED (m/sec)	POWDER FLOW RATE (g/min)	GAS FLOW RATE (L/min)	TD (sec)	M_P (g)	M_D (g)	Powder Efficiency (μ) %
1	3.0	0.01	5.64	4	6	0.564	0.51	90.43
2	3.0	0.02	5.64	4	3	0.282	0.25	88.65
3	3.0	0.03	5.64	4	2	0.188	0.16	85.11
4	3.0	0.04	5.64	4	1.5	0.141	0.12	85.11
5	3.0	0.05	5.64	4	1.2	0.1128	0.09	79.79
6	3.0	0.06	5.64	4	1	0.094	0.07	74.47
7	3.0	0.07	5.64	4	0.86	0.081	0.06	74.47
8	3.0	0.08	5.64	4	0.75	0.071	0.05	70.92
9	3.0	0.09	5.64	4	0.67	0.063	0.04	63.83
10	3.0	0.1	5.64	4	0.6	0.057	0.03	53.19
11	3.0	0.005	5.64	4	12	1.128	0.28	24.82

This is due to the fact that the dwelling time reduces as the scanning speed increases and the time is not sufficient to melt most of the powders. The highest efficiency of 90.43% was obtained at the scanning speed of 0.01m/sec. To be able to conclude that the scanning speed can be reduced indefinitely to have higher efficiency another experiment was conducted at a much lower scanning speed of 0.005m/sec with other processing parameter remaining constant. This additional experiment reveal that there is limit to which the scanning speed can be reduced to obtain higher material efficiency as shown in Fig. 7. The efficiency obtained is much lower than the least obtained at the highest scanning speed of 0.1m/sec. this can be attributed to the fact that more powder is been delivered into the substrate that the laser is able to melt despite

efficiency of 90.43% below and above this scanning speed the powder efficiency will drop. The future work will be to further investigate the best scanning speed to produce approximately 100% efficiency. This will be done by investigating the scanning speed between 0.005m/sec to 0.01m/s. This becomes very necessary because of the result of this study. The sharp drop in efficiency between 0.01m/sec and 0.005m/sec shows there are some important activities taking place between this two scanning speed. The further study will provide information about fine tuning the optimum scanning speed.

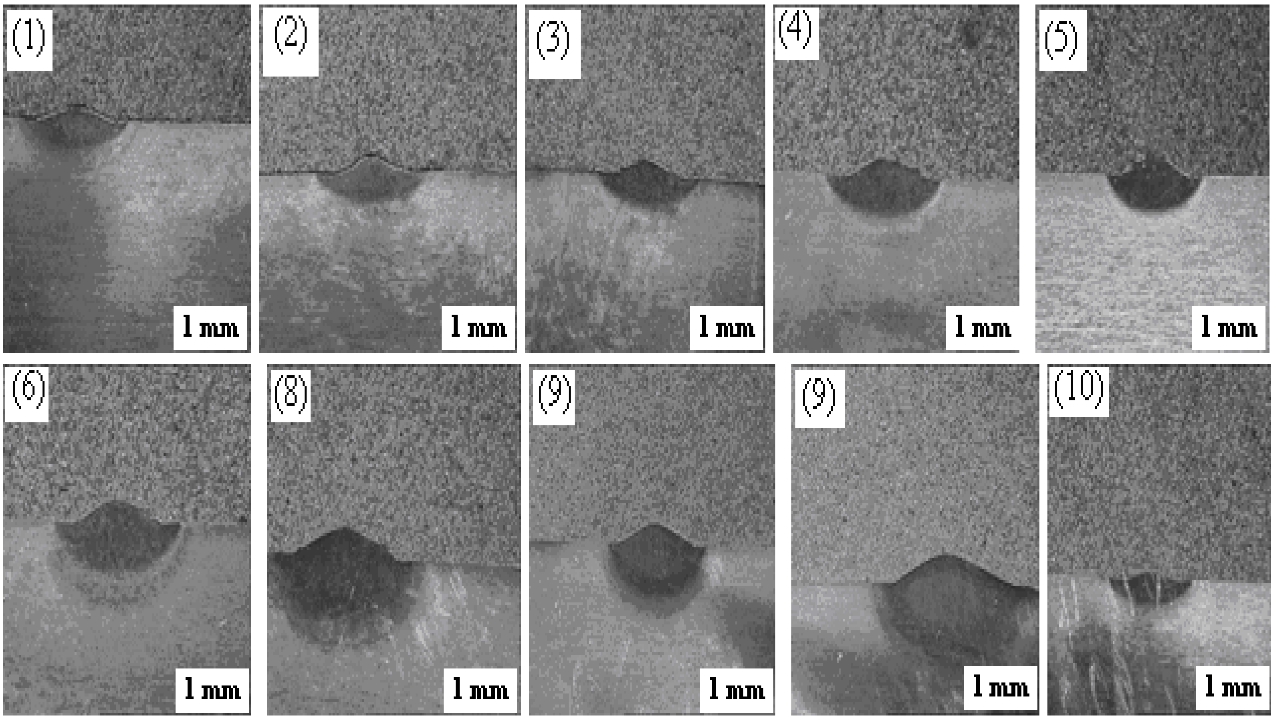

Fig. 4 The macrographs of the samples 1 to 10

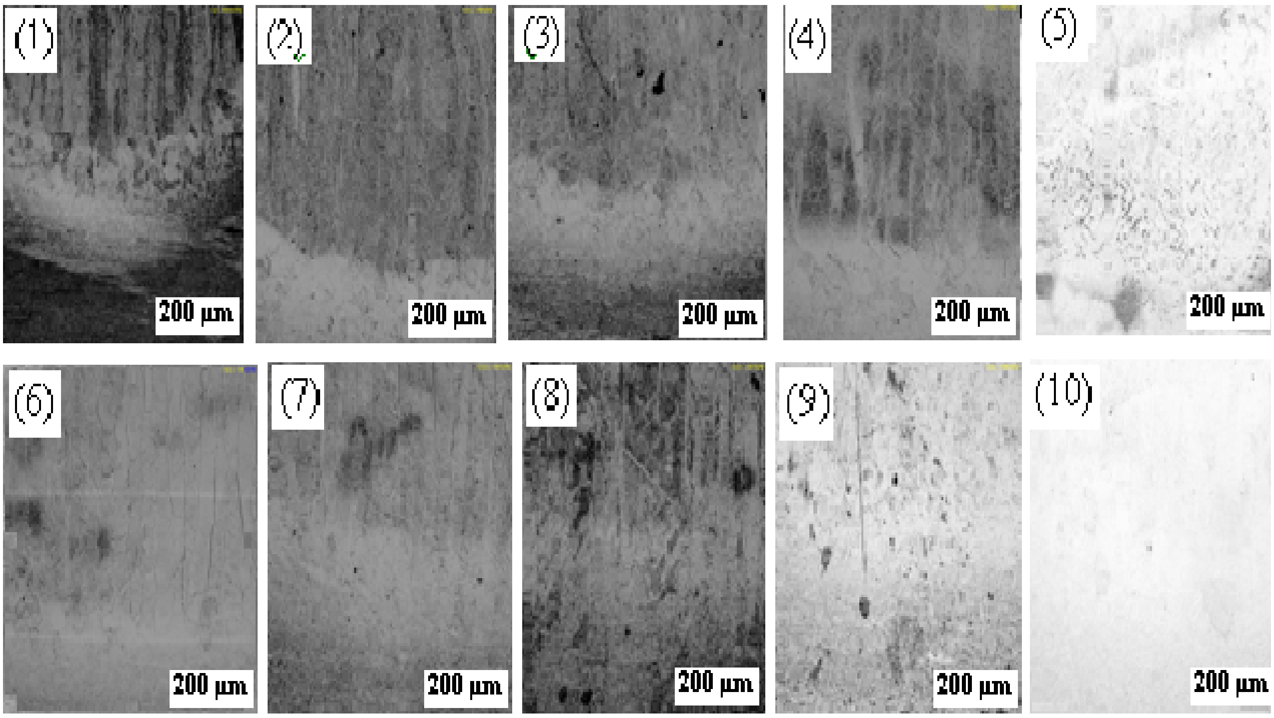

Fig. 5 The micrographs of the samples 1 to 10

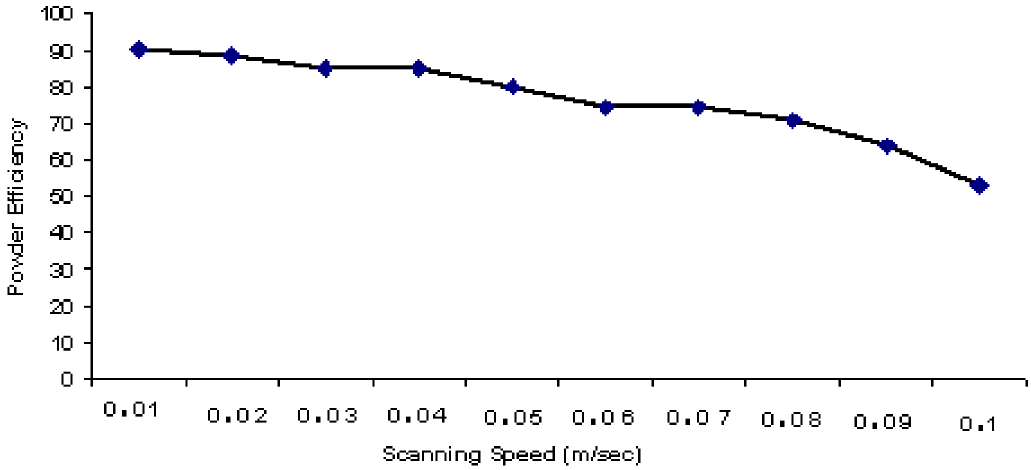

Fig. 6 Plot of powder efficiency against Scanning speed for Samples 1 to 10

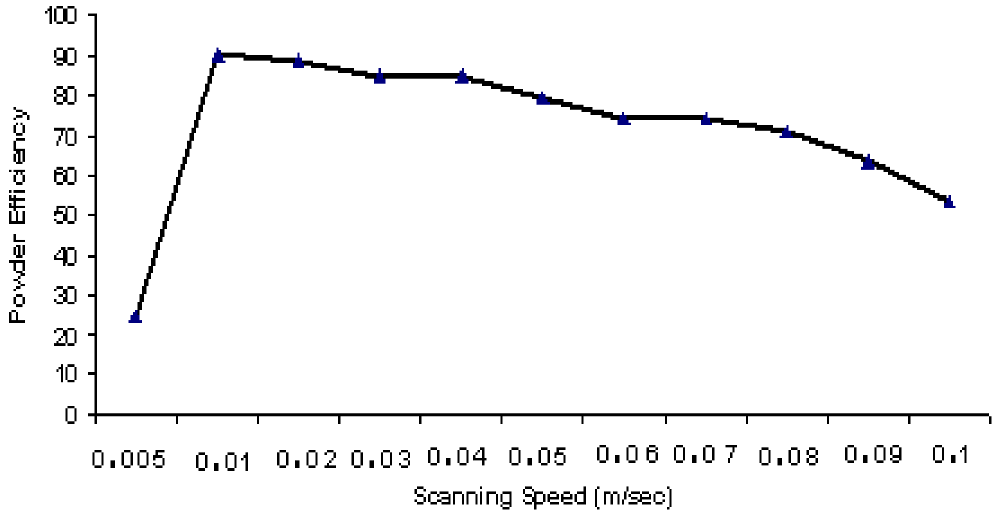

Fig. 7 Plot of powder efficiency against Scanning speed for Samples 1 to 11

REFERENCES

[1] M.N. Ahsana, A.J. Pinkerton, R.J. Moatb, and J. Shackleton, A comparative study of laser direct metal deposition characteristics using gas and plasma-atomized Ti–6Al–4V powders, Materials Science and Engineering A 528 (2011) 7648– 7657.

[2] A. R. Machado, and J. Wallbank, Machining of Titanium and Its Alloys: A Review, Proceedings of the Institution of Mechanical Engineers Part B: Management and Engineering Manufacture, Vol. 204, No. 11, 2005, pp. 53-60.

[3] C.W. Fink, An overview of additive manufacturing. Part II, AMMTIAC Quarterly. 2009, 4(3):7 - 10.

[4] DT. Pham, C. Ji and CC. Dimov, Layered manufacturing technologies, Proc. of the International Conf. on New Forming Tech., ICNFT, Sept. 2004, Harbin, China, pp. 317–324.

[5] J. Allen, An Investigation into the Comparative Costs of Additive Manufacture vs. Machine from Solid for Aero Engine Parts. In Cost Effective Manufacture via Net-Shape Processing, Meeting Proceedings RTO-MP-AVT-139, Paper 17, 2006, pp. 1 – 10.

[6] P. Bergan, Implementation of laser repair processes for navy aluminum components, Proceeding of Diminishing Manufacturing Sources and Material Shortages Conference (DMSMS), 2000, available at: http://smaplab.ri.uah.edu/Smaptest/Conferences/ dmsms2K/papers/decamp.pdf, accessed on 13th July 2012.

[7] W. Zhou, and K.G. Chew, Effect of welding on impact toughness of butt-joints in a titanium alloy, Materials Science and Engineering A347, 2003 ,pp.180-185.

[8] A.J. Pinkerton, and L. Li, (2004). Multiple-layer cladding of stainless steel using a high- powered diode laser: an experimental investigation of the process.

[9] W.M. Steen, (2003). Laser Material Processing, Springer-Verlag.