Laser Power and Scanning Speed Influence on Intermetallic and Wear Behaviour of Laser Metal Deposited Titanium Alloy Composite

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Abstract — Ti6Al4V, an aerospace alloy, is the most widely produced titanium alloy because of its exciting properties such as high strength to weight ratio and excellent corrosion resistance properties. Despite these properties of this titanium alloy, the wear property is poor because of its chemical property that makes it react with other material it comes in contact with. Therefore, there is need for surface modification of the titanium alloy if it will be used in application where it will come in contact will other material in rubbing or sliding action. TiC has been used to improve the wear resistance property of titanium alloy with success. Laser metal deposition (LMD) process, an additive manufacturing process, is an advanced manufacturing process for achieving part with the desired surface property as well as for producing complex part directly from the three dimensional (3D) computer aided design (CAD) model of the part. Processing parameter has a great influence on the resulting properties of the deposited part using LMD. This research investigates the influence of laser power and scanning speed on the in-situ formation of titanium aluminide (Ti_3Al) during laser metal deposition of TiC/Ti6Al4V composite and its overall effect on the wear resistance behaviour of the deposited composites. The laser power was changed between 1.8 and 3.0 kW and the scanning speed was changed between 0.05 and 0.1 m/s. It was found that, the intermetallic produced increased as the scanning speed was reduced from 0.1 to 0.05 m/s. The intermetallic formed at low scanning speed was found to decrease as the laser power was increased from 1.8 to 3.0 kW, while it was found to increase as the laser power was increased at higher scanning speed. The wear resistance property increases as the intermetallic formation increases. This study revealed that finding an optimum process parameter is important in achieving better properties in laser metal deposition of TiC/Ti6Al4V composite. The optimum process parameter was found to be at laser power of 1.8 kW and scanning speed of 0.05 m/s based on the process parameters considered in this study.

Keywords— Intermetallic, laser metal deposition, processing parameters, titanium aluminide, Ti_3Al, Wear.

Manuscript received June 19, 2016; revised August 6, 2016. This work was supported by the University of Johannesburg Research Council and L'Oreal-UNESCO for Women in Science.

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I. INTRODUCTION

Titanium and its alloy possess excellent properties that make them to be favoured in a number of industries. The properties include high strength to weight ratio, high corrosion resistance and ability to retain these properties at elevated temperature [1]. A number of industries that take advantage of these properties include automobile, aerospace, petrochemical, biomedical and marine industry [2,3]. Ti6Al4V is the most widely used titanium alloy because it has the highest strength to weight ratio and it is often referred to as the workhorse of the industry [4]. In spite of these exciting properties, the wear resistance property is poor which makes it to be necessary to perform surface modification so as to improve the wear resistance property. Also as a result of the poor wear resistance property of titanium, the processing of this material using the traditional manufacturing process is challenging [5]. additive manufacturing technology is an excellent alternative manufacturing method for processing titanium and its alloys.

Laser metal deposition process (LMD) is an important additive manufacturing technology with a lot of potentials. LMD is capable of producing a three dimensional (3D) part directly from the 3D computer aided design (CAD) digital model of the part by adding materials layer after layer [6]. LMD is also capable of repairing high valued parts that were not repairable or prohibitive to repair in the past [7, 8]. The flexibility offered by LMD in its ability to handle more than one material at the same time makes it useful for the production of part with functionally graded materials [9]. Difficult to machine materials such as titanium and its alloys can easily be processed using the LMD process. LMD has been applied in surface modification of titanium and its alloys in the literature [10-14].

in this study, the effect of laser power and scanning speed on the formation of titanium aluminide Ti_3Al produced in-situ during laser metal deposition of Ti6Al4V/TiC composite and its influence on wear properties was investigated. The laser power was varied between 1.8 and 3.0 kW while the scanning speed was varied between 0.05 and 0.1 m/s. The powder flow rate and the gas flow rate were fixed at 4 g/min and 4 l/min respectively. The results are presented and discussed in detail.

II. EXPERIMENTAL PROCEDURE

The laser metal deposition process consists of a 4.0 kW Nd-YAG laser operated in continuous mod and at wavelength of 1.06 μm, coaxial powder delivery nozzles.

All these were attached to the end effector of a Kuka robot. The spot size was maintained at 2mm and at a focal length 195 mm above the substrate. The materials used for the experiments are the argon gas for the powder delivery and for shielding the deposited part. The powders used was Ti6Al4V powder and TiC. Ti6Al4V sheet of 5mm thick was used as a substrate. The titanium alloy-Ti6Al4V powder is of 99.6 % purity and was supplied by VSMPO-AVISMA Corporation, Russia. The TiC powder is of 99.5% purity and it was supplied by F.J. Brodmann and Co., L.L.C., Louisiana. The substrate is a 99.6% pure Ti6Al4V. The powder particle size of the Ti6Al4V is between the range of 150 and 250 µm while the TiC powder is of particle size range below 60 µm. The substrate was sandblasted and then washed with acetone before the deposition process. The two powders were put in a separate hopper of the twin powder feeder and the powders were delivered into the melt-pool simultaneously. The powder flow rates were set such as to deliver 50 W% of TiC powder and 50 W% Ti6Al4V powder. . Multiple tracks of six layers were produced at 50 % overlap. The laser power was varied between 1.8 kW and 3.0 kW and the scanning speed was varied between 0.05 and 0.10 m/s. the powder flow rate and the gas flow rate were maintained at that values of 4 g/min and 4 l/min throughout the experiments. The processing parameters are presented in Table I.

Table I. Processing parameters

Sample No.	Laser power (kW)	Scanning speed (m/s)
1	3.0	0.05
2	1.8	0.10
3	1.8	0.05
4	3.0	0.10

The Argon gas was used to keep the oxygen level in the improvised glove box below 10 ppm during the deposition process in order to prevent the atmospheric oxygen and nitrogen from contaminating the deposited samples. The laser metal deposition process was achieved by the laser beam creating a melt-pool on the surface of the substrate and then the Ti6Al4V powder and the TiC powder are fed into the melt-pool. The wear tests were carried out on the deposited samples under the dry condition (no lubrication) using a ball on disk arrangement on a Cert tribotester. A Tungsten Carbide ball of 10 mm diameter was used as the counter face at a load of 25 N, a reciprocating frequency of 20 Hz and at a sliding distance of 2000 mm. The wear test was performed according to the ASTM G133 – 05(2010) Standard [15]. X-ray diffraction (XRD) were performed on the samples to determine the phases present in the samples.

III. Results and Discussion

The results of the effect of laser power and scanning speed on Ti_3Al produced in-situ and the wear volume produced are presented in Table II . The graph of Ti_3Al and wear volume against the laser power at a scanning speed of 0.05 m/s is shown in Figure 1.

Table II. Results of the % Ti_3Al and wear volume

Sample No.	Laser power (kW)	Scanning speed (m/s)	% Ti_3Al	Wear volume (mm^3)
1	3.0	0.05	12.6	0.063
2	1.8	0.10	5.8	0.092
3	1.8	0.05	15.2	0.054
4	3.0	0.10	7.3	0.077

The intermetallic. Ti_3Al, formed in-situ is found to decrease as the laser power was increased. The high quantity of the Ti_3Al intermetallic seen at low laser power as shown in Fig 1 was produced as a result of the solid state phase transformation of the primary α phase structure at the low laser power and the low scanning speed. At the low laser power, the melt-pool created is a small thereby causing the solidification and cooling rate to be faster which promotes the formation of the larger percentage of the Ti_3Al formed. As the power was increased, the melt pool created becomes larger and the solidification and the cooling rate is slower. This results in low percentage of Ti_3Al intermetallic produced. The wear volume on the other hand is lower at low laser power which corresponds to the large quantity of Ti_3Al intermetallic. Also, the wear volume increase as the laser power was increased which also correspond to the low Ti_3Al intermetallic produced at the low laser power. The Ti_3Al intermetallic was seen to improve the wear resistance property of the Ti6Al4V/TiC composite. The Ti_3Al intermetallic may have combined with the unmelted powder to form fine powder as the sliding action progresses. The fine powder formed a protective layer in between the two sliding surfaces thereby reducing the wear action of the rubbing surfaces.

The result seen at a higher scanning speed is found to be different from what was observed at low scanning speed as shown in Fig. 2. The wear volume is seen to be reduced as the laser power was increased while the Ti_3Al intermetallic was seen to increase as the laser power was increased. Although the percentages of the Ti_3Al intermetallic produced are much lower than those produced at the higher scanning speed as seen in Fig. 1.

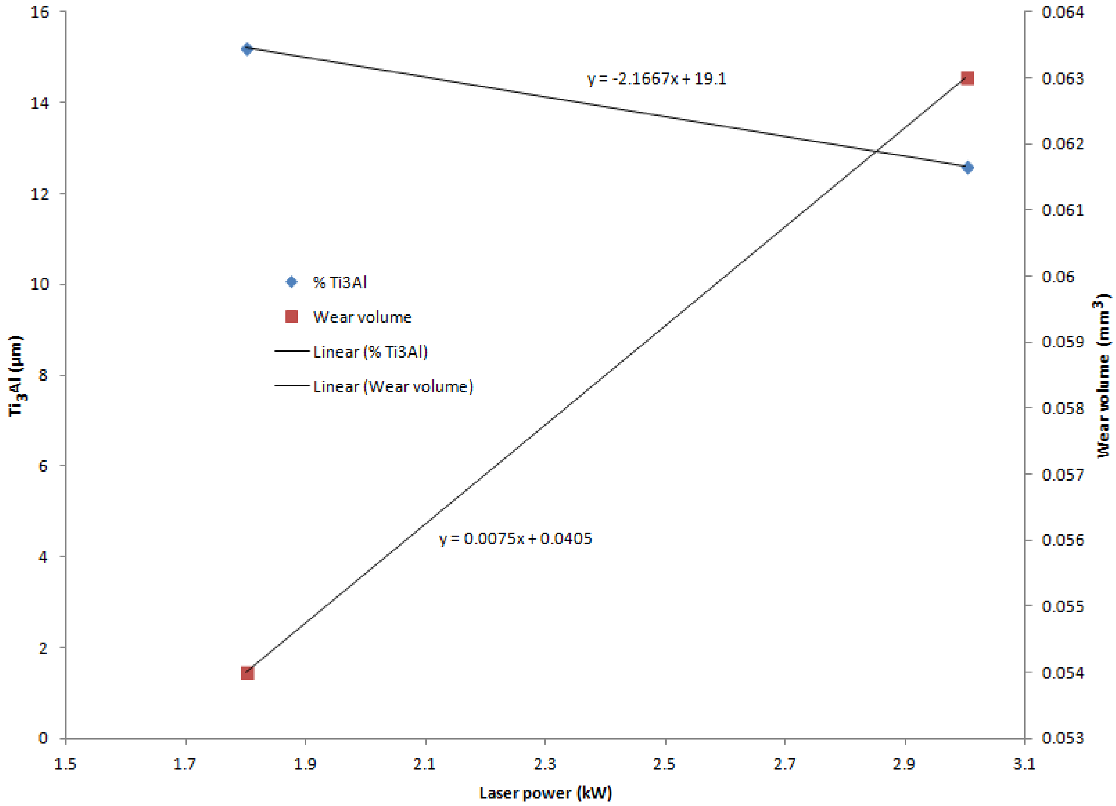

Fig. 1. The graph of the titanium aluminide and wear volume versus the laser power at a scanning speed of 0.05 m/s

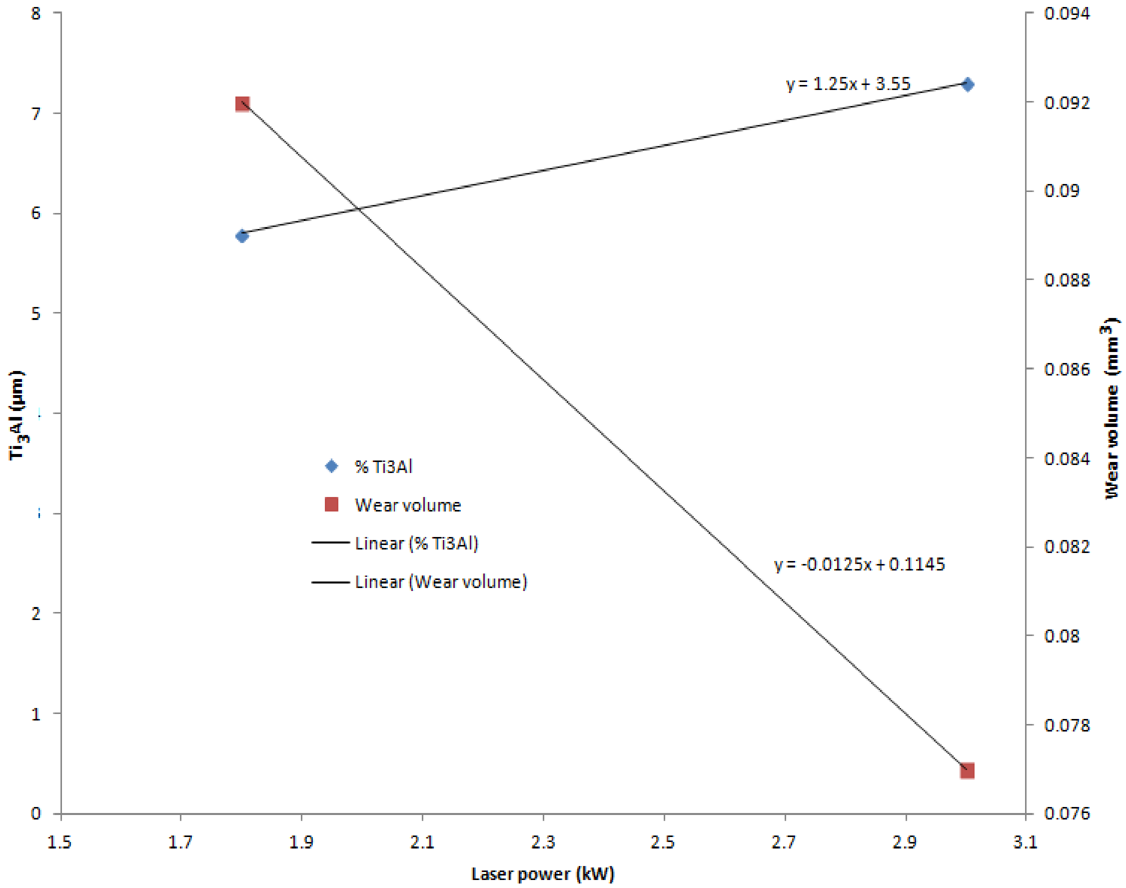

Fig. 2. The graph of the titanium aluminide and wear volume against the laser power at a scanning speed of 1.0 m/s

The reason for the reducing wear volume as the laser power was increased at high scanning speed is that the melt-pool created at high laser power is moderately small due to the low laser-material -interaction time which results in rapid solidification and cooling rate that promotes higher Ti_3Al intermetallic formation. The lower percentage of Ti_3Al intermetallic seen at low laser power could be as a result of very low laser-material-interaction time that could result in improper melting of the deposited powder which could not favour the large formation of the Ti_3Al intermetallic.

IV CONCLUSSION

The Ti6Al4V is an important aerospace alloy with excellent properties that make them to be favoured in a number of human Endeavour. Despite the excellent properties of Ti6Al4V, the wear resistance property is poor and that is why surface modification is often performed to improve the wear resistance property. This study investigates the effect of laser power and scanning speed on the Ti_3Al intermetallic formation in-situ during the laser metal deposition process of Ti6Al4V/TiC composite and its effect on the wear resistance property was also studied. The study reveals that at low scanning speed, as the laser power was increased the Ti_3Al intermetallic formed was reducing and wear resistance was also found to be reducing. At high scanning speed, the Ti_3Al intermetallic formed in-situ was found to be increased and the wear resistance was also found to be increased. It can be concluded that the formation of Ti_3Al intermetallic in-situ helps to improve the wear resistance property of the Ti6Al4V/TiC composite.

Acknowledgments

This work was supported by University of Johannesburg research council (URC) and the L'OREAL-UNESCO for Women in Science.

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