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Microstructures and Dry Sliding Wear Characteristics of the Laser Metal Deposited Ti6Al4V/Cu Composites

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Abstract

This paper reports on the investigations conducted on the evolving microstructures and the dry sliding wear of the laser deposited Ti6Al4V/Cu composites. Some selected process parameters were used for the experiments. The laser powers were chosen between 1300 W and 1600 W; scanning speeds were selected between 0.30 m/min and 0.72 m/min while other parameters are as specified in the experimental matrix. It was found that all the composites produced showed good and high-quality microstructures and they exhibited very low or no fusion zones which were as a result of the selected process parameters used. The composite produced at a laser power of 1397 W and a scanning speed of 0.3 m/min was found to show the lowest percentage of wear volume and coefficient of friction; and happened due to the martensitic structure formed during cooling. Results obtained showed that the poor abrasive wear of titanium alloy has been improved with the addition of copper into their lattices.

Keywords: dry sliding wear, laser metal deposition; microstructures; Ti6Al4V/Cu composites; wear characteristics

1. Introduction

To most of the researchers, titanium and its alloys have been regarded as one of the productive and mostly used metal for industrial applications. The aerospace, marine, automobile, biomedical and sport industries are strongly in demand of titanium due to the exposition of their properties. According to the structural alloy hand book, 1982, these alloys have found limited use in the mechanical engineering

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applications because of their poor tribological properties such as poor abrasive wear resistance, poor fretting behavior and high coefficient of friction. This poor fretting behaviour of titanium alloys could be improved and enhanced by applying different surface treatments and coatings. As stated by Gogia et al., 1992; Tian and Nemoto, 1997, the perfection in the mechanical properties of titanium and its alloys such as strength have been greatly accomplished through the addition of alloying metal composites. Fu et al., 1998 stipulated that there are four main mechanisms that could be used to improving the tribological behaviour of titanium alloys and these are: increase the surface roughness, decrease in the coefficient of friction, increase in the hardness and the induction of a compressive residual stress. Erinosho et al., 2014 added little percentage of Copper (Cu) to titanium alloy (Ti6Al4V) at varying laser power during laser metal deposition (LMD) operation to improve the composites hardness values. Murray, 1992 conducted a research study on Ti-Cu and revealed that the Ti-Cu composites exhibited precipitation strengthening and the solid solubility of Cu in Ti was reduced as the temperature decreases, and there exist an intermetallic compound Ti_2Cu in their composites. Kikuchi et al., 2003 stated that the cast Ti-Cu alloys with the optimism of developing their alloys for dental casting have better mechanical properties than the unalloyed commercially pure titanium. Quite a number of studies have been conducted on LMD of commercially pure titanium, Ti6Al4V composites with other metals, but Ti6Al4V/Cu composites are very few in the literature.

This research work therefore emphatically portrays the influence laser metal deposition process on the evolving microstructures and dry sliding wear behaviour on some of the selected process parameters from the design of experimental runs on the studies used for the Ti6Al4V/Cu composites.

2. Experimental techniques

The research work was conducted using the laser techniques and was conducted at the National Laser Centre of Council of Scientific Industrial Research (NLC-CSIR), Pretoria, South Africa. The LMD of the composites was accomplished on the Ytterbium Laser System equipment (YLS-2000-TR). This equipment runs at the utmost power of 2000 Watts and uses a Kuka robot for its function.

2.1. MATERIALS AND METHODOLOGY

A 99.6 % square-shaped titanium alloy grade 5 with a volumetric dimension of 102 X 102 X 7.45 mm^3 was used as the substrate. The substrate was grit blasted to prepare the surface for good metallurgical bonding and remove surface contaminants. After the grit blasting, the substrate was sanitized with acetone and dehydrated. The two powders used for these experiments are Ti6Al4V and Cu powders with particle sizes varied between 150 and 200 µm. The powders were fed from two different hoppers and flow through the hose connections to the nozzle end with the aid of the carrier gas that created the atomization. Erinosho et al., 2014 gave a typical illustration of how the two powders were positioned.

Table 1 shows the process parameters used for the experiments. The parameters were selected from the preliminary studies after running a design expert program to select the desirable parameters.

Table 1. Experiment matrix

Sample Name	Laser Power (W)	Scanning Speed (m/min)	Powder Flow Rate (rpm)		Gas Flow Rate (l/min)	
			Ti6Al4V	Cu	Ti6Al4V	Cu
DE1	1600	0.59	2.4	0.1	2.95	2.0
DE2	1600	0.63	2.4	0.1	2.95	2.0
DE3	1582	0.72	2.4	0.1	2.95	2.0
DE4	1600	0.50	2.3	0.2	2.95	2.0
DE5	1397	0.30	2.3	0.2	2.93	2.0
DE6	1576	0.60	1.8	0.2	2.90	2.0
DE7	1600	0.59	1.8	0.2	2.90	2.0
DE8	1397	0.30	2.4	Nil	2.90	Nil

The selected samples were labelled from DE1 to DE8. The samples labelled DE1 to DE7 are having a combination of Ti6Al4V and Cu while DE8 is for Ti6Al4V without Cu inclusion. The beam diameter of 4 mm and a nozzle standoff distance of 12 mm were used for all the experiments. According to E3-11 ASTM standard, all the samples were grinded, polished and etched.

2.2. MICROSTRUCTURE

Prior to optical microscopy observation, the Kroll's reagent was prepared with 100 ml H_2O, 2-3 ml HF and 4-6 ml HNO_3. This was prepared according to Struers application note of metallurgical preparation of titanium (Accessed from the website, 2013). The samples were etched for 10 - 15 seconds, wet with acetone, rinsed under clean running water and dried off. The microstructures of all the etched samples were observed under the BX51M Olympus optical microscope.

2.3. DRY SLIDING WEAR TESTS

The dry sliding wear test was carried out on the micro tribometer module, CETR UTM-2 operating with linear reciprocating motion drive. This method of testing employs a flat lower specimen and a ball-shaped upper specimen made of 9.5 mm diameter tungsten carbide ball that slides against the specimen or sample and move relative to one another in a linear, back and forth sliding motion. The dry sliding wear tests were carried out on the deposited Ti6Al4V/Cu samples according to the ASTM G133-05 for determining the sliding wear of metals.

2.4. WEAR SCAR CHARACTERIZATION

The wear scar was characterized for the length of the stroke, the width of the wear scar and the depth of wear (groove) that were made on the surface of the deposited samples. The width of wear scar is measured from the Scanning Electron Microscope (SEM) image at low magnification.

3. Results and discussion

The results obtained from the microstructural evaluation and the dry sliding wear analysis are presented and discussed in this section.

3.1. *MICROSTRUCTURAL EVALUATION*

The microstructures of all the samples were observed under the optical microscope at low and high magnifications. Figs 1 show the macrographs and the microstructures of sample DE1 produced at a laser power of 1600 W and a scanning speed of 0.59 m/min respectively.

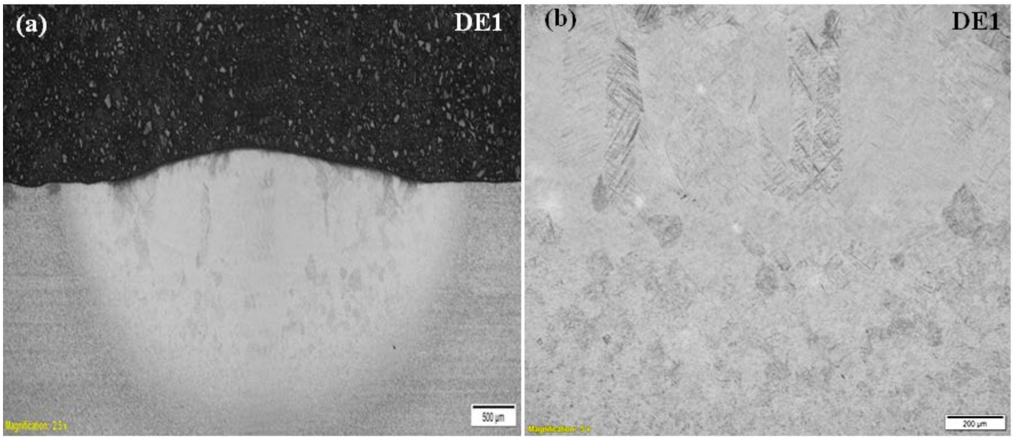

Fig. 1. Macrographs and Microstructures of the deposited Ti6Al4V/Cu composite: (a and b) Sample DE1 with parameters 1600 W and 0.59 m/min at low and high magnification

An investigation was carried out on the evolving microstructures on samples DE1 to DE8. Fig 1(a) shows the macrograph of sample DE1 at low magnification. It was observed that the fusion zone (FZ) was not pronounced which indicates the existence of a good deposit and shows no porosity. Fig 1(b) shows the formation of macroscopic banding and disappears as it grows towards the FZ. There was also the formation of widmanstettan structures which occurred as a result of the cooling rate which was revealed by Erinosho et al., 2014. The grain boundaries at the deposit were wider and prominent than the FZ and the heat affected zone (HAZ) which were due to the differences in the distribution of the heat input as the heat travels from the top of the deposit to the FZ and then to the HAZ.

3.2. *SEM ANALYSIS OF WEAR TRACK*

The SEM images of the wear track surfaces for Ti6Al4V/Cu composites and Ti6Al4V composites were analysed. From the SEM that was carried out on the wear track of the samples, the length of the stroke and the width of the wear scar were measured; and the depth of wear was determined from the wear result analysed by the system.

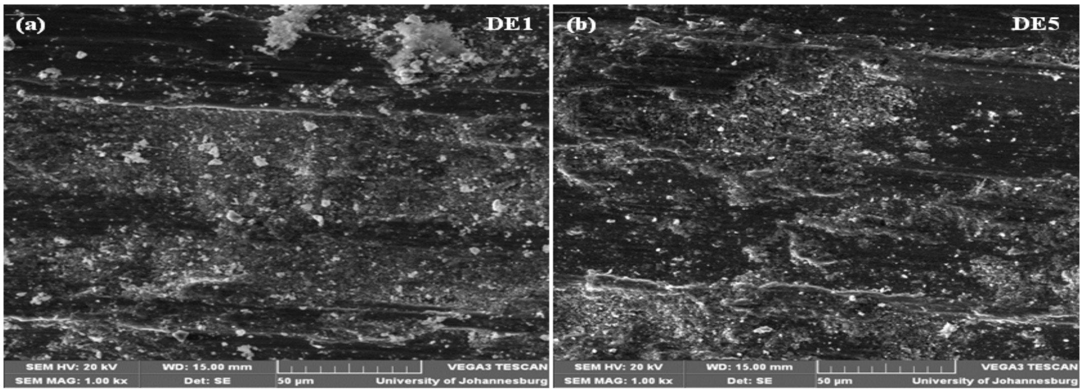

Fig. 2. SEM images of the wear track of the deposited composites: (a) sample DE1 at laser power of 1600 W and scanning speed of 0.59 m/min; (b) sample DE5 at laser power of 1397 W and scanning speed of 0.30 m/min respectively

The wear surfaces of the deposited Ti6Al4V/Cu composites of samples DE1 and DE5 are presented in Fig 2(a) and (b). Wear debris were found in all the wear samples. The wear debris of sample DE5 was more pronounced compared to the other samples and this phenomenon was due to the loss of ductility after the deposition process and the basal planes of the hexagonal α-phase were more densed after cooling. The coefficient of friction at this point was very low as compared to other samples DE1, DE6 and DE8. The Cu content included in the composites distorted the lattices of Ti6Al4V thereby influencing the mechanical properties of the Ti6Al4V based composites. Sample DE1 also shows a loss of ductility but not as that of sample DE5.

3.3. *WEAR CHARACTERIZATION*

The wear characteristics of the deposited composites were measured and achieved through the width of wear, length of stroke and the wear of depth produced by the tungsten carbide ball. Fig 3 illustrates the histogram plot of the width of wear, length of stroke and the wear of depth against all the samples produced in this study.

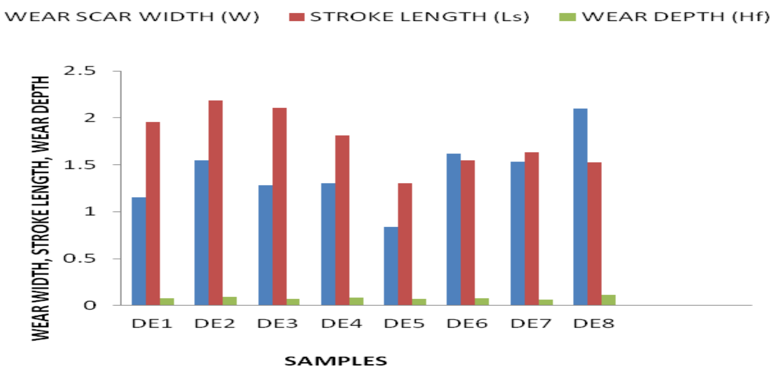

Fig. 3. Histogram of the wear width, stroke length and wear depth

Sample DE8 produced at a laser power of 1397 W and a scanning speed of 0.3 m/min shows the highest wear width and wears depth and demonstrates a greater ductility as compared to other samples with Cu inclusion. Sample DE5 shows the lowest wear width and wear depth. This occurrence shows that the width and depth of wear is directly proportional to the wear volume and vice versa. The presence of Cu has really influenced the wear property of Ti6Al4V.

4. Conclusions

As far as technology is concerned today, LMD has gained acceptance in both the aerospace, marine and other associated industries. The improvement in the mechanical properties of Ti6Al4V has been achieved with the addition of Cu through the evolving characterizations of the Ti6Al4V/Cu composites. Good inherent properties with no porosity were achieved in all the samples after laser metal depositions. The formation of Widmanstettan structures occurred as a result of the rate of cooling and the grain boundaries were more pronounced and prominent at the main deposit than the fusion zone and the heat affected zone; and these occurred as a result of the diversities in the heat input. The wear volume of the Ti6Al4V/Cu composite of sample DE5 produced with the laser power of 1397 W and the scanning speed of 0.30 m/min was less pronounced than the other samples and this phenomenon was due to the loss of ductility after the deposition process.

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