EFFECT OF SCANNING SPEED ON THE MATERIAL CHARACTERIZATIONS OF LASER DEPOSITED TITANIUM ALLOY AND COPPER

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Abstract - Laser Metal Deposition (LMD) belongs to a class of advanced materials that are manufactured using additive manufacturing techniques. Titanium alloy (T64) is commonly used for aerospace, marine, biomedical and automotive components due to its combined amazing properties. Copper (Cu) is a beta phase stabilizer and its behaviour in the alloy has been studied. This paper focuses on the influence of scanning speed on the laser deposited titanium alloy and copper composites ($T64_{50}Cu_{50}$). Equal weight proportion of $T64_{50}Cu_{50}$ was deposited on T64 substrate by varying the scanning speed from 0.5 m/min to 2 m/min while other parameters are kept constant. The microstructural behaviour and the microhardness measurement have been investigated and reported. The interaction time between the nozzle and the substrate during laser deposition determines on the depth and width of the heat affected zone; the melt pool created on the substrate has also influenced the meld of the participating powders to the substrate. The relationship between the scanning speed and the deposited area has provided a way of controlling the desired deposit range during manufacturing or the repair of a component.

Keywords - Laser metal deposition, microstructure, micro-hardness measurements, $T64_{50}Cu_{50}$ composite.

I. INTRODUCTION

Engineering materials have played an important role in the devolvement of our society. Advanced materials such as engineering alloys, structural ceramics, fibers and polymers have been manufactured by applying the scientific principle and knowledge for the purpose of quality production. Based on this, most of the production must meet the demand requirement for the design of new and existing product [1]. Thus, a certain desired specific characteristics to the advanced metal are achievable with the alloying process [2]. Powder metallurgy is introduced for repair on complex shaped components; however, it has deal with a great flexibility to meet the demands of low and high volume manufacturing [3]. Additive manufacturing (AM) processes or rapid prototyping [4] stand a chance to change the manufacturing industry from using conventional methods to the areas of design freedom and manufacturing capabilities. In traditional manufacturing methods, the removal of the material to produce the required geometry has resulted in waste of material and machining tool wear. Thus, this limitation has make AM to be a unique and adopted method of manufacturing [5]. Laser Additive Manufacturing is an interesting process for titanium aerospace components due to the ability to greatly reduce the production lead-time and buy-to-fly ratio while maintaining the quality produced by conventional methods [6]. In general, it has allowed new design approaches for lightweight structures that were impossible for the conventional manufacturing process. Although, the surface furnish and the dimensional accuracy may be inferior due to poor repeatability of the technique especially on a micro dimension scale for large components [7]. During the laser cladding of Ti6Al4V alloy on the same solid material substrate to study the dilution process, clad geometry, and varying process parameters, low laser power and high scanning speed can improve the quality of the clad deposited on the substrate [8].

This paper reports the effect of scanning on the material characterizations of laser deposited 50 weight percent (wt.%) of Ti6Al4V alloy and 50 weight percent (wt.%) of Cu. The macrograph effect and the micro-hardness measurement were investigated on the samples. The scanning speeds were varied from 0.5 m/min to 2 m/min while the laser power of 1000 W, the powder flow rate of 1 rpm and the gas flow rate of 2 l/min are kept constant.

II. EXPERIMENTAL TECHNIQUES

The laser deposition took place at the National Laser Centre, Council for Scientific and Industrial Research, South Africa. Through the co-axial three way nozzle, single track deposition of 50 wt.% Ti6Al4V alloy and 50 wt. % Cu ($T64_{50}Cu_{50}$) were made on titanium alloy plate using a beam diameter of 4 mm.

All the samples were ground, polished and etched, following the guidelines in the Struers application note of metallurgical preparation of titanium [9]. The etchant was prepared with 100 ml of water (H_2O), 5 ml of Nitric acid (HNO_3) and 3 ml of Hydrofluoric acid

(HF). Thus, each sample was slightly deep into the Kroll's reagent for 15 seconds prior to microstructural surveillance on the Olympus BX51M microscope

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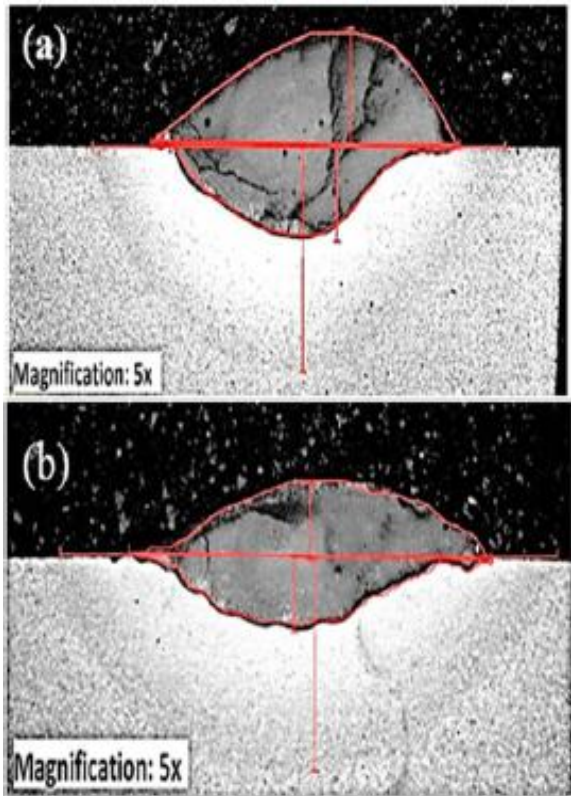
Sample Name	Scanning Speed (m/min)	Laser Power (W)	Powder feed rate (rpm)		Gas Flow (l/min)
			Ti6Al4V (50 wt.%)	Cu (50 wt.%)	
A1	0.5	1000	1	1	2
B1	1	1000	1	1	2
C1	1.5	1000	1	1	2
D1	2.0	1000	1	1	2

Table 1: Experimental matrix

The microhardness test was carried out on the unetched samples using the TIME Group Inc TH722 Vickers. Ten indentations with 150 µm interval were made from the top of the deposit to the substrate for dwell time of 15 seconds using a force of 500 gf according to the E384 -11e1 ASTM standard [10].

III. RESULTS AND DISCUSSION

The macroscopic analyses conducted on the LMD samples from A1 to D1 are presented. Figs. 1 (a) to (d) show the macrograph of samples A1, B1, C1 and D1 deposited with a laser power of 1000 W and varying scanning speed of 0.5 m/min, 1 m/min, 1.5 m/min and 2.0 m/min respectively.



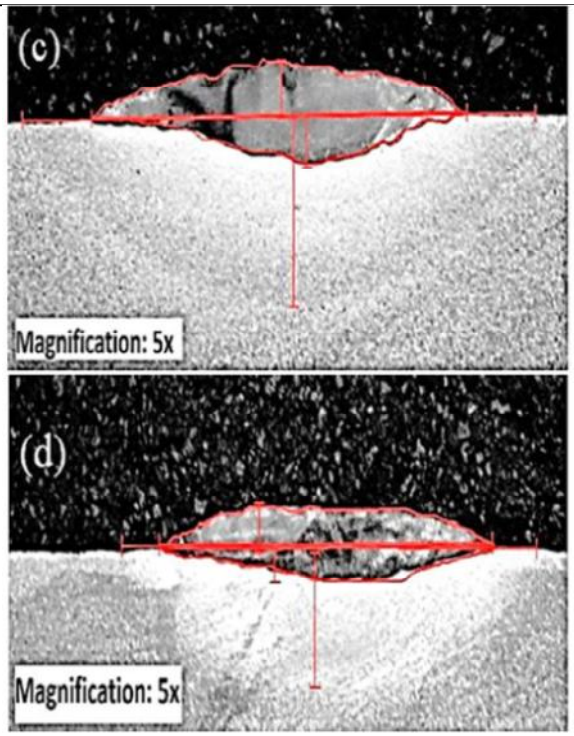
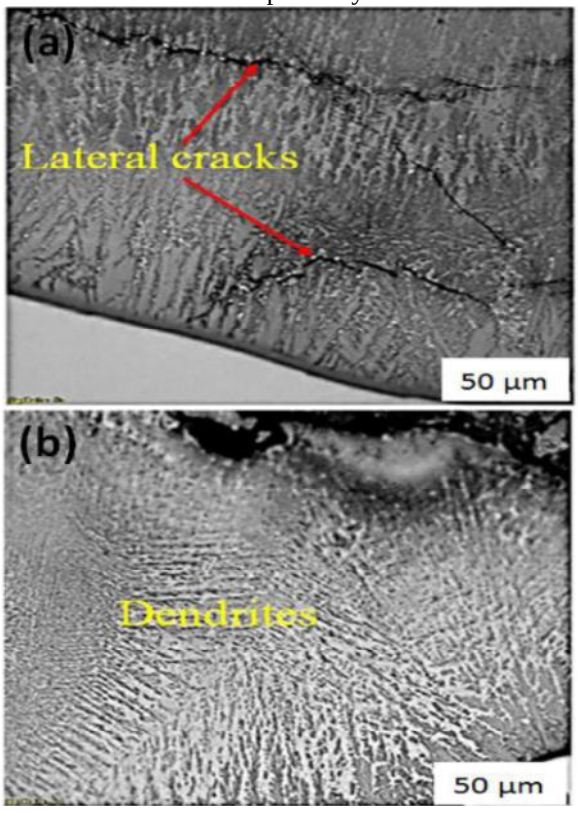


Fig.1. Macrograph analyses of laser deposited $T64_{50}Cu_{50}$ Sample, (a) Sample A1 deposited with scanning speed of 0.5 m/min; (b) Sample B1 deposited with scanning speed of 1.0 m/min; (c) Sample C1 deposited with scanning speed of 1.5 m/min; (d) Sample D1 deposited with scanning speed of 2.0 m/min

Figs. 2 (a) to (d) display the microstructures of samples A1 to D1 deposited at a laser power of 1000 W and scanning speeds of 0.5 m/min, 1.0 m/min, 1.5 m/min and 2.0 m/min respectively.



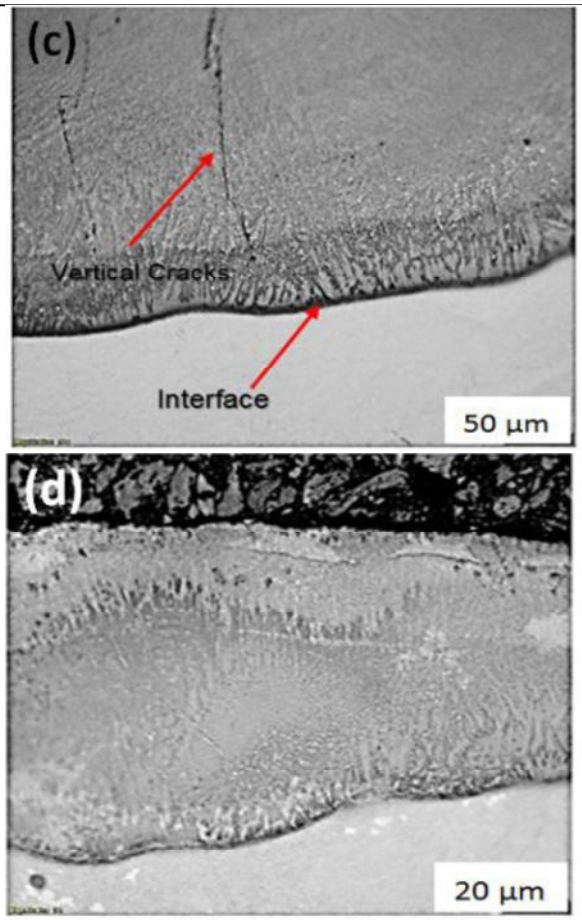


Fig. 2. Microstructural analyses of laser deposited $T64_{50}Cu_{50}$ Sample, (a) Sample A1 deposited with scanning speed of 0.5 m/min; (b) Sample B1 deposited with scanning speed of 1.0 m/min; (c) Sample C1 deposited with scanning speed of 1.5 m/min; (d) Sample D1 deposited with scanning speed of 2.0 m/min

As observed in Fig. 1, the area of deposition decreases as the scanning speed was increased. Sample A1 deposited at a scanning speed of 0.5 m/min and laser power of 1000 W depicts the highest deposition area of 250842.8 μm^2 while sample D1 deposited at a scanning speed of 2.0 m/min and laser power of 1000 W shows the lowest deposition area of 577.2 μm^2. At the highest scanning speed used, the interaction time between the depositing powders and the substrate was more to create large volume of $T64_{50}Cu_{50}$ deposit. Other measurements were also made on the laser deposited $T64_{50}Cu_{50}$ such as dilution percentage, deposition height and width, fusion depth, depth and width of heat affected zone (HAZ). Table 2 summarises the measurement conducted on the macrographs of the laser deposited $T64_{50}Cu_{50}$ from samples A1 to D1 respectively.

The deposition width and height decreases as the scanning speed was increased. The time of interaction during deposition determines on the depth and width of the HAZ in the substrate. The melt pool created in the substrate has also contributed to the fusion of the powders. More melt pool is created at low scanning speed that allows a large volume of deposition and vice versa. Due to the 50 wt % of Cu introduced, dendrites are pronounced in all the deposited samples. The dendrites in sample A1 are more distinct in the deposit and elongated towards the fusion zone. Some lateral cracks were formed towards the fusion zone as a result of differences in the thermal expansion of the powders.

Geometry	Sample Name			
	A1	B1	C1	D1
Deposition Area (μm^2)	250842.80	89021.25	33668.27	577.20
Dilution Percentage (%)	39.02	43.89	39.56	39.32
Deposition Height (µm)	289.68	134.64	63.92	9.25
Fusion Depth (µm)	235.28	134.64	42.16	8.16
HAZ Depth (µm)	565.77	379.44	175.44	30.06
Deposition Width (µm)	1392.65	1083.63	873.12	99.29
HAZ Width (µm)	1865.92	1489.21	1086.65	135.73

Table 2: Geometrical summary of the $T64_{50}Cu_{50}$ deposit

Fig. 2 shows the microhardness profiling of samples A1 to D1 from the top of the deposited $T64_{50}Cu_{50}$ to the substrate.

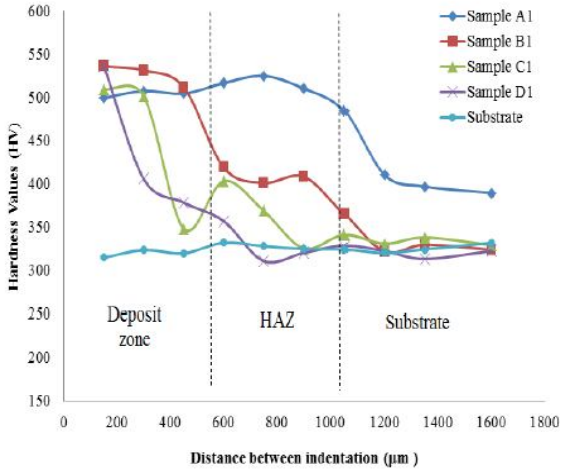


Fig. 2. Hardness profiling of laser deposited $T64_{50}Cu_{50}$ samples

The hardness values were obtained for the deposited layers, the heat affected zone and the substrate. A fall in hardness value was observed in samples B1, C1 and D1 from the top of the deposit and down to the substrate. Only sample A1 deposited at a laser power of 1000 W and scanning speed of 0.5 m/min experiences a rise in the hardness values and later drop after the heat affected zone. This behaviour could be due to more interaction time with the laser and the effect of heat sink. Similarly, the deepest HAZ exhibited by sample A1 is as a result of the high laser

exposure time at low scanning speed per unit area. The first three indentations in samples A1 and B1 fell between 504 HV and 536 HV respectively. The average hardness values of samples A1, B1, C1 and D1 are 474 ± 51 HV, 414 ± 80 HV, 379 ± 67 HV and 359 ± 66 HV respectively. Among the laser deposited samples, sample A1 deposited exhibits the highest hardness value. The hardness values of all the samples were improved compared to the 324 ± 5 HV of the substrate. It can be deduced that an increase in scanning speed leads to a decrease in the hardness values of the deposited $T64_{50}Cu_{50}$ samples.

CONCLUSIONS

The laser deposition of equal proportion of $T64_{50}Cu_{50}$ composites was greatly achieved and the effect of scanning speed has been investigated. The interaction time during the deposition determines on the depth and width of the heat affected zone within the substrate. The melt pool created in the substrate has also contributed to the blend of the T64 and Cu powders. Dendrites of Cu within the lattices of T64 were observed in all the deposited samples. Sample A1 deposited with a laser power of 1000 W and scanning speed of 0.5 m/min exhibited the highest hardness value of 474 ± 51 HV while sample D1 deposited with a laser power of 1000 W and scanning speed of 2.0 m/min exhibited the lowest hardness value of 359 ± 66 HV. Due to the differences in thermal expansion of both powders, lateral cracks were developed in the deposit during the cooling.

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