EVALUATION OF HATCH DISTANCE AND POWDER FEED RATE EFFECTS IN TI-6AL-4V ALLOY DEVELOPED BY LMD TECHNIQUE

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ABSTRACT

Laser metal deposition provides various benefits over traditional manufacturing, and has since become the research hotspot, as demand for advanced manufacturing persists. The effects of process parameter variation on structural integrity and dimensional accuracy of Ti-6Al-4V alloy fabricated through laser metal deposition was investigated. The laser power, scan speed and gas feed rate were kept constant while overlap distance was varied between 0,3375 and 1,0125mm, and the powder feed rate was varied between 1,6 and 3,8g/min. The density of samples was studied by Archimedes method using ethanol as a wetting liquid, and dimensions were evaluated using a digital Vernier calliper. The microstructure and morphology were examined by an optical microscope (OM). The microhardness and densification of specimen were evaluated using Vickers microhardness tester and Archimedes method, respectively. The results revealed an increase in density with an increase in overlap spacing, and the opposite effect was observed for increasing powder flowrate, whereby an increase in powder flowrate was found to decrease density. The evolution of large pores was favoured by higher powder feed rate at constant overlap spaces. In addition, the microhardness of all samples was found to exceed the conventionally fabricated Ti-6Al-4V alloy.

Keywords: Laser Metal Deposition, Overlap Spacing; Powder Feed-rate, Structural Integrity, Geometric Accuracy

1. INTRODUCTION

Laser metal deposition (LMD) is one of the laser-based directed energy deposition (DED) methods, which incorporates powders locally injected into the melt pool formed by laser irradiation to fabricate 3 dimensional components. The deposition occurs in a layer-by-layer fashion following the tracks directly from computer-aided design (CAD) data [1], [2]. In recent years, there has been a growing interest in the process as the technology provides the ability to fabricate complex material geometries, which are normally unattainable through traditional manufacturing techniques [3]. Addition to this are countless other benefits, including permitting powder recycling, optimal raw material usage, reduced raw material stock size, fewer machine operations, reduced hard tooling requirements and reduced lead times [4]. Despite these significant advantages over conventional manufacturing, further advantages are hindered by the limited understanding of the correlation between process parameters, interaction mechanisms and resultant material properties [5]. The processing parameters such as laser power, scan speed, powder feed rate, feedstock quality, overlap distance and shielding gas flow rate greatly influence the properties of the deposited components. The above-mentioned properties comprise of deposition's dimensional accuracy, microstructure and mechanical characteristics [6]–[8]. Therefore, success of building a component of good quality, structural integrity and relatively precise geometry lies within the proper parameter selection and heat transfer dependant solidification mechanism, as well as microstructural evolutions [1], [9], [10].

Titanium and its alloys are advanced materials with an excellent combination of desirable properties such as a high specific strength, superior corrosion resistance and good biocompatibility [11]. Ti-6Al-4V, the most popular aerospace material, is known to be difficult to machine and expensive [12]. As a result, this material is a good candidate for near net shape processes such as LMD fabrication technologies as they require minimal post processing [6]. The materials compatible with laser-assisted additive manufacturing are still limited, fortunately titanium and its alloys are prominent to the process, thus enabling them to reap the benefits offered by LAM fabrication [13]. However, attempting to improve the extent of these benefits requires a more advanced knowledge of the process' underlying physics, which is yet to be established [6].

In considering the importance of process parameters regarding structural integrity and geometrical accuracy for achieving a high-quality component, Qiu et al. [14] focused on a parametric study to investigate the influence of processing and design conditions on structural integrity, geometrical integrity, microstructure and mechanical

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properties of large Ti-6Al-4V structures fabricated through LENS. Results revealed that a lower powder feed rate coupled with a high laser power produce minimal porosity, decreasing power resulted in the formation of lack-of-fusion pores, due to incomplete melting of powders. In addition, authors found the geometry and height design-to-build ratio to be sensitive to specified laser nozzle moving step along the build height direction. In another study, Kummailil et al. [15] observed that an increase in mass flow rate or laser power resulted in an increase in the deposition height while increasing hatch-spacing or scan speed resulted in a reversed consequence. In addition, the authors pointed out that the effects of the mass flow rate and scan speed were significantly greater than the other parameters. According to Shukla et al. [6], the complexity of interactions occurring during deposition requires studying fewer (one or two) process parameters to ensure a proper grasp of knowledge.

The primary aim of the present work is to study and optimize LENS process parameters (particularly powder feed rate and overlap distance) to improve the relative density and design-to-part dimensional accuracy of the laser metal deposited Ti-6Al-4V alloy components. The former will help improve mechanical performance by reducing porosity while the later decreases the number of discarded components in production.

2. METHODOLOGY

The laser metal deposition technique was used to fabricate a total of four samples from gas atomised Ti-6Al-4V spherical powder particle size range of 40-90 µm. The test samples were built on 75 mm*75 mm*40 mm Ti-6Al-4V plate using a LENS system, which is mounted with a 1 KW IPG fibre laser. Laser deposition test work was performed at the Council for Scientific and Industrial Research (CSIR) National Laser Centre (NLC) in Pretoria. The deposition process parameters are shown in Table 1. The powder feed rate was altered between 1.6 and 3.8 g/min, while the varied hatch distance ranged from 0.3375mm and 1.0125mm. The substrates were sandblasted and cleaned with acetone prior to deposition in order to improve laser absorption and remove excess dirt. The Olympus BX51M optical microscope was used to capture the micrographs for evaluation of the effect of selected process parameters on microstructure. Density measurements were done by Archimedes method by means of a (equipment details here) using distilled water as the wetting liquid. The microhardness of the test of samples was conducted using a Vickers diamond base indenter (equipment details here). The dimensional accuracy of square samples was studied by comparing the design heights of 5,06mm with the build dimension achieved through Vernier Caliper measurements. The design dimensions of square samples were 10mm*10mm*5mm, and this was compared to the actual heights to measure the percentage over-build of LAM deposition, under-build was reported as negative over-build.

Table 1: LENS Processing Parameters used for deposition of samples.

Sample	Laser power (W)	Scan speed (mm/s)	Powder feed rate (g/min)	Hatch Spacing (mm)
A-1	300	16,93	1,6	0,3375
A-2	300	16,93	3.8	0,3375
B-1	300	16,93	1.6	1,0125
B-2	300	16,93	3.8	1,0125

3. RESULTS AND DISCUSSIONS

The results revealed that both the overlap distance and powder feed rate have an influence on structural integrity of deposits as seen by density variations shown in. The hatch spacing had a relatively less influence on densities of samples, especially at low powder feed rates, in contrast to the powder feed rate which shown significantly greater effect on densities as seen in the micrographs found in figure 1. A comparison of samples at the same hatch distance revealed that the higher powder flow rates produced elevated sample heights in comparison to their counter parts. This is shown in Table 1. The results revealed a significant height difference between samples fabricated at similar conditions but varied hatch spacing, with larger overlap distances producing samples with relatively shorter heights. Sample A1 was closest to the designed height with a slight over-build of 0,12mm, sample B2 followed with an -0,6mm under-build, followed by sample A1 at 1,1mm over-builds and sample B1 at -2.49 under-build.

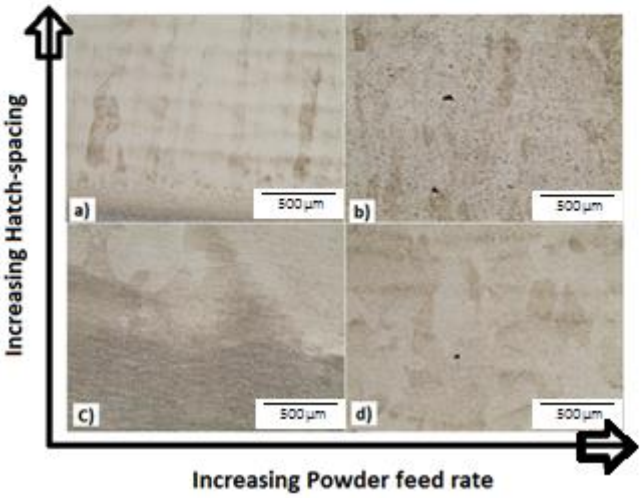

Figure 1: OM micrographs of Ti-6Al-4V by LENS at different process conditions a) B-1, b) B-2 c) A-1 and d) A-2

Illustrated in Figure 1 are the optical micrographs of the specimen deposited at varied hatch spaces and powder feed rates. Figure 1a) and c) reveals a defect/pore free morphology while Figure 1b) shows a relatively more pores distributed across the whole surface sample body. The presence of these pores is attributed to a high powder feed rate, which results in incomplete melting of powder, thus leading to the formation of lack-of-fusion pores. Figure 1d) shows a micrograph with pores to some degree though relatively less porous than b). The higher degree of porosity found in Figure 1b) as compared to d) though processed at similar powder feed rate serves as evidence of the influence of hatch spacing on the structural integrity of the builds. The microhardness profile, densities and height measurements of the built samples is shown in Figure 2

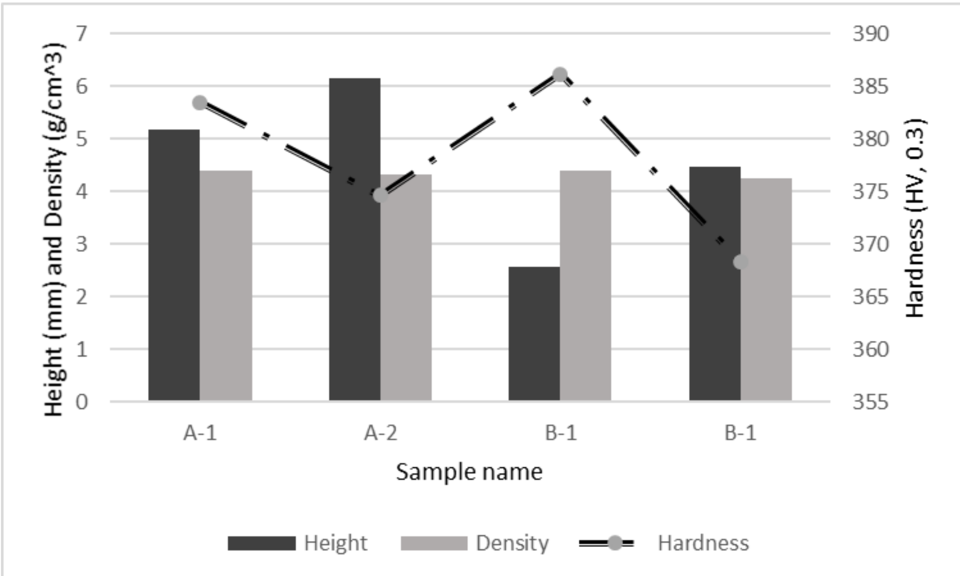

Figure 2: Microhardness variation, Density and Height measurements of the samples fabricated at different processing conditions.

The microhardness profile of the samples is shown in **Error! Reference source not found.**. All the observed hardness values of the samples were above that of conventionally fabricated Ti-6Al-4V alloy (344 HV). Furthermore, the results reveal that the hardness substantially reduces with an increase in scan speed and improves with decreasing hatch spacing at with greatest reduction in hardness observed for samples lower powder feed rates.

Sample	Height (mm)	overbuild (mm)	Density (g/cm^3)
A-1	5.18	0,18	4,4102
A-2	6.16	1.1	4.3272

B-1	2.57	-2,43	4.3976
B-2	4.46	-0.6	4.2487

4. CONCLUSION

- The LENS additive manufacturing technique can produce depositions with similar properties to the commercially available manufacturing processes, as the hardness values obtained through the LENS process were higher than conventional manufacturing practices.
- Increasing the powder feed rate reduces the density; while increasing hatch spacing has a negative influence on densification when deposition is carried out at higher powder feed rates.
- The most accurate build in terms of design-to-build dimensions measured by heights is seen in the sample A1, built at the powder feed rate of 1,6 g/min and 0.3375 mm hatch spacing.

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