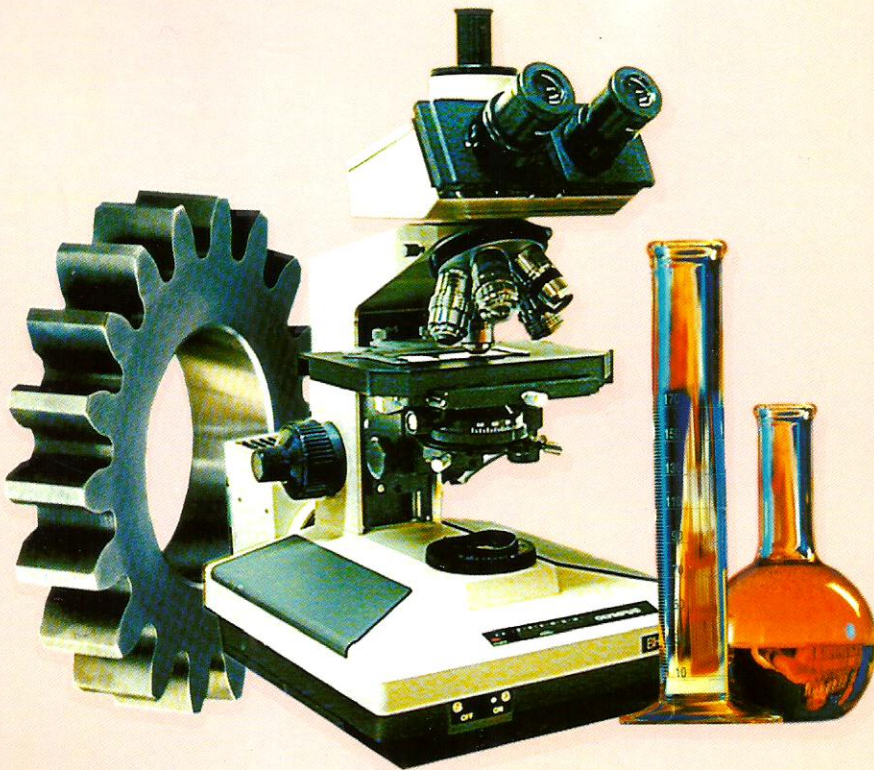


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Laser Metal Deposition of Titanium Alloy: Effect of Laser Power on Surface Finish

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Abstract

Laser Metal Deposition (LMD) is a non-traditional manufacturing process used for production of intricate parts by successive addition of layers of material. However, obtaining processed parts with good surface finish always poses great challenges. In this study the effects of the processing parameter in LMD processes on the surface characteristics of Titanium Alloy (Ti-6Al- 4V) was investigated. The response function considered was Surface Roughness (R_a) and (R_{max}), while the LMD input parameter that was varied is the laser power. The scanning speed, powder flow rate and gas flow rate were kept constant. The investigation showed that the highest laser power of 3.2 KW gave the lowest surface roughness of $0.7\mu m$ which implies that for better surface, high laser power is required.

Keywords - Laser Metal Deposition, Non-traditional manufacturing process, Scanning speed, Surface roughness, Titanium alloy.

Introduction

Titanium alloy (Ti-6Al-4V) finds its uses in many industrial applications such as aeronautical, aerospace, ship building, chemical and nuclear industries because of its high strength to weight and stiffness to weight ratios. However, its affinity to the cutting tool materials and intrinsic high elevated temperature behaviour make the Titanium a difficult-to-machine material by conventional machining methods [1-4].

Conventional processes for machining difficult-to-machine materials encounter many hindrances, hence the processes are becoming insufficient as they are associated with poor machining efficiency leading to poor surface finish among other output responses. Non-traditional manufacturing processes, such as LMD provide better alternatives for difficult-to-machine materials [5]. LMD is one of the non-traditional manufacturing techniques (i.e. additive manufacturing technology) used for complex machined parts by successive addition of materials layer by layer [6-7]. Among its area of application are repair and tooling in aerospace as well as automotive industries [8-10].

LMD process is achieved by generating pool of melt on the substrate by laser beam wherein powder or wire is fed into the melt pool. This technique can be used to produce functionally graded material (FGMs), both as coatings and as a complex three-dimensional object [11]. The complex part is produced directly from the three dimensional (3D) image of the part [12]. The LMD process is yet to be fully understood and the resulting poor surface roughness obtained from the manufactured part needs to be fully investigated.

Many research works on the effect of processing parameters on surface roughness in LMD machining have been published [13-16]. Among these published works are Ahn et al., [15] which reported the prediction of surface roughness using data measurement and interpolation. Zhu et al., [17] studied the benefit of positioning the powder focus below the melt-pool and the quality of the surface finish. The study showed that a melt-pool enlargement was the main contributor to optimum surface finish produced. In a related work of Alimardani et al., [18], it was reported that controlling the melt-pool dimension and temperature can improve the surface finish. Influence of particle size on surface quality has also been correlated in a similar study performed by Spierings et al. [14].

This study investigated the influence of laser power on the surface finish variations in laser metal deposited on Titanium alloy (Ti-6Al-4V). The laser

power was varied from 0.8 kW to 3.2 kW, while scanning speed, powder and gas flow rates were kept constant.

Experimentation

The material used in the work was Titanium alloy (Ti-6Al-4V) substrate of 99.6% pure having dimensions of 72 x 72 x 5 mm. The Ti-6Al-4V powder used also has 99.6% purity having particles size of between 150 and 200 μm . The Ti-6Al-4V substrate was sandblasted and cleaned with acetone in order to roughen the surface so as to improve the laser energy absorption process.

The experimental set-up (Fig. 1) consists of a Kuka robot carrying an Nd-YAG laser head (by Rofin) in its end effector. To prevent the environmental effect (scaling of sample surface) on the deposited samples, a glove box (Fig. 1) was improvised and attached to prevent contamination of the surface finish produced. The glove box was filled with argon gas. The laser metal deposition process was achieved by the laser beam creating a melt pool on the substrate and then the Ti-6Al-4V powder was delivered into the melt pool through the coaxial powder nozzles attached to the end-effector. A solid track of Ti-6Al-4V metal was created upon solidification of the melt pool. The laser power used varied between 0.8 and 3.2 kW, while the laser beam was maintained at a focal distance of 195 mm above the Ti-6Al-4V substrate to maintain the laser beam at a constant diameter of 2 mm.

The Ti-6Al-4V powder flow rate of 2 g/min, scanning speed of 0.005 m/s and the gas flow rate of 2 l/min were kept constant throughout the LMD process. The experimental matrix is shown in Table 1.

The microstructure of the substrate used in this study as observed under the Olympus optical microscope is shown in Figure 3a and the morphology of the Ti-6Al-4V powder is shown in Figure 3b. The microstructure of the Ti-6Al-4V is characterised by alpha and beta grain structure. The lighter part in the microstructure represents the alpha grains while the darker parts are the beta grains. The morphology of the powder is characterised by spherical shaped gas atomized powder (Fig. 3).

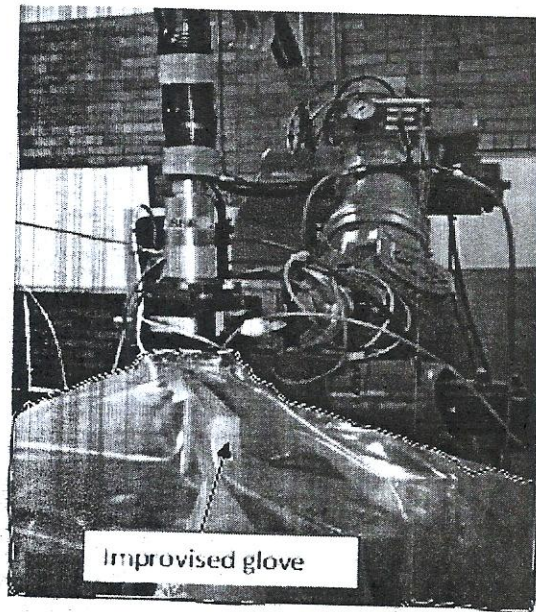


Figure 1. Experimental Set-up for LMD process

Table 1 Experimental matrix

Substrate Deposition Path	Laser Power (kW)
A	0.8
B	1.2
C	1.6
D	2.0
E	2.4
F	2.8
G	3.2

Evaluation of Surface Roughness

After the deposition process, the substrate deposition paths on the Ti-6AL-4V samples were cleaned with acetone and dried with hot air in preparation for surface roughness measurement. The surface roughness was carried out

in line with “BS EN ISO 4288:1998” standard. The stylus surface analyzer by Jenoptik, equipped with Hommel-map 6.2 software (Fig. 2) was used for the surface roughness measurement. The effective measured length was kept at 4.8 mm. The cut-off length of the surface measured was maintained at 0.8 mm; and the measuring range was at 400 μm with a sliding speed of 0.50 mm/s. Five measurements were taken on each of the samples, and the arithmetic average of the 2D roughness profiles (R_a) was recorded for each samples.

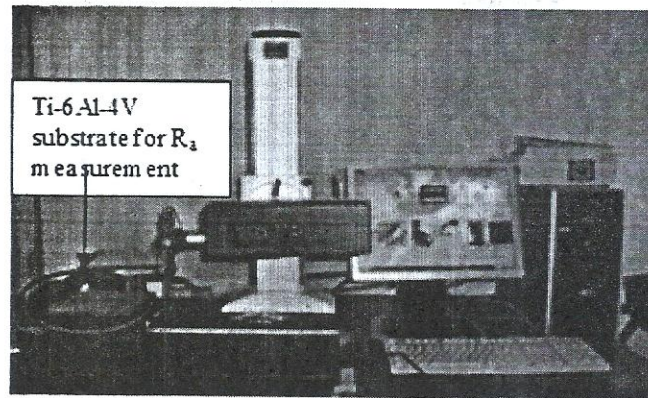
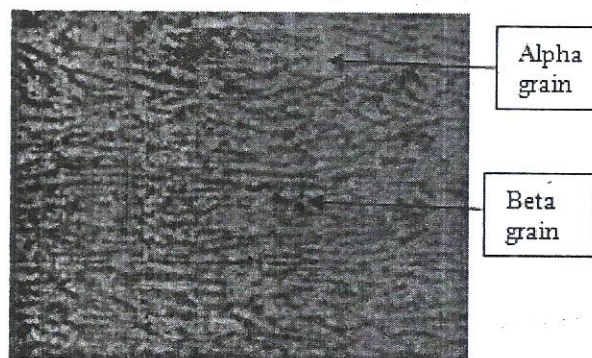
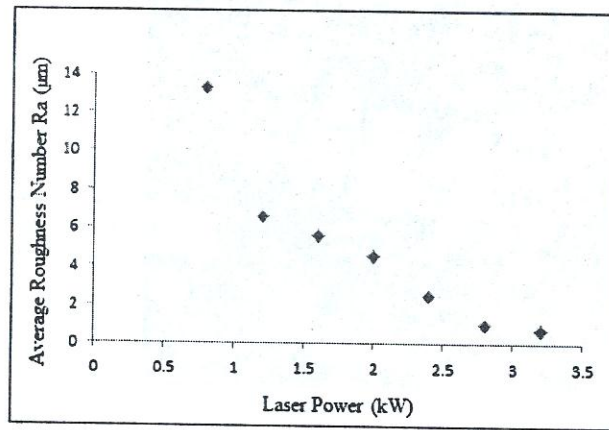


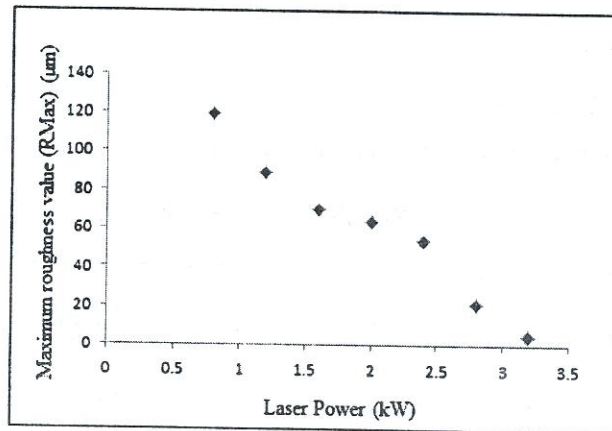
Figure 2 Jenoptik surface profiler used



(a)



(a)



(b)

Figure 4 The plot of (a) Ra against laser power (b) Rmax against laser power

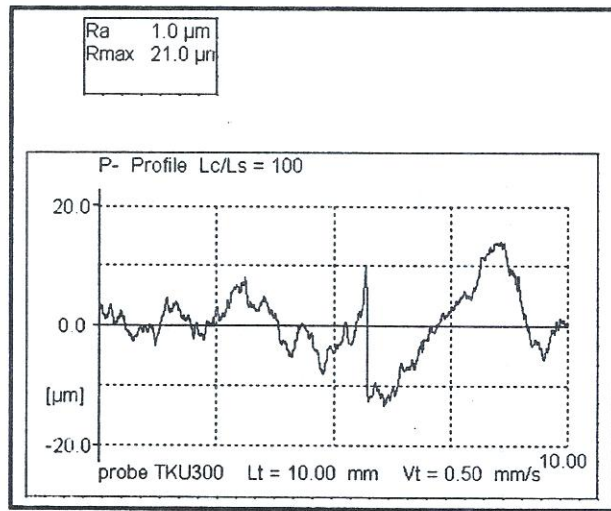
The plot of variations in average roughness value (R_a) against the laser power is shown in Figure 4a, while the plot of the maximum roughness value against the laser power is shown in Figure 4b. The graph of surface roughness of the parent material, samples A, B, D, F and G are presented in Figure 5a-5f respectively.

The surface roughness is found to be better (smoother) as laser power increases (Figure 4a). The resulting better surface roughness is because as the laser power increases, there is more available power that resulted in high heat intensity for proper melting and diffusion of the deposited Ti-6Al-4V powder into the outer surface layer of the substrate. This proper melting of the powder at higher laser power gives rise to a smoother surface thereby reducing the average roughness number. At low laser power, not all the powder delivered from the powder nozzle was completely melted thereby causing some of the unmelted powder particles to cause the higher roughness number (waviness) observed. This result is in line with the works of Spierings, et al, 2010 and Ahn et al, 2009.

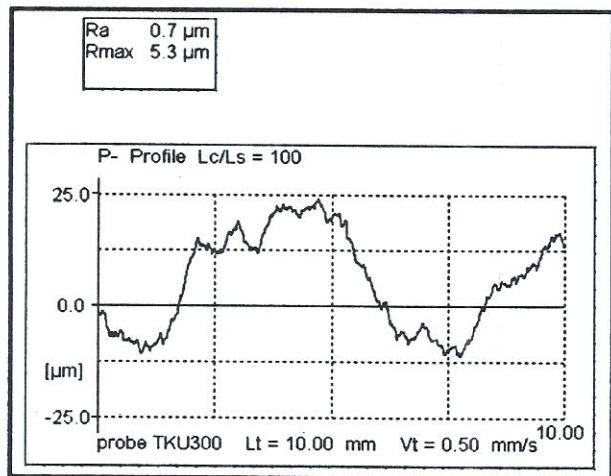
In line with the observation of average surface roughness, the maximum roughness number $R_{\max}$ at low laser power was very high as a result of the unmelted Ti-6Al-4V powder particles observed at low laser power. These effects are shown Figures 5b to 5f.

Conclusion

An experimental study has been conducted to investigate the influence of laser power on surface roughness in laser metal deposition of Titanium alloy Ti-6Al-4V. The LMD parameters used were seven variables laser power with constant values of scanning speed, powder and gas flow rates. The conclusion drawn from the study is that a better surface finish can be achieved in laser metal deposition process by using a high laser power with the right combination of input parameters.



(e)



(f)

Figure 5 Surface profile of the (a) substrate and sample at laser power of (b) 0.8 kW (c) 1.2 kW (d) 2.0kW (e) 2.8 kW (f) 3.2 kW

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