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Influence of laser melting process parameters on surface roughness behavior for SS316L powder

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Abstract

In this study an investigation of surface roughness and morphology is presented for laser melted stainless steel 316L alloy. Single track formation has been produced using different laser process parameters. Furthermore, macro, micro and surface roughness has been analyzed using metallurgical tools like macroscope, Scanning Electron Microscope (SEM) and surface profilometer. The paper investigates the key contributing factors influencing the surface roughness of the laser melted part. The surface morphology and roughness provides valuable information to improve the surface quality of laser melted parts.

Keywords: Laser Melting Process, AISI 316 L powder, Surface Roughness

1. Introduction

Laser melting process still faces an apparent limitation in terms of surface quality if compared to some of the conventional metal manufacturing processes

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such as machining. Surface quality and its surface roughness and corrosion properties are greatly influenced by the process parameters of laser melting process [1-3]. However the layer thickness can be reduced to improve the surface finish. In addition, obtaining a good surface finish presents a very important issue in laser melting process since poor surface lead to mechanical failure as well as lower corrosion resistance. It also leads to long and expensive post-finishing operations [4, 5]. Furthermore, a smooth surface is limited by the "balling" phenomenon that occurs during laser melting [6, 7]. The balling effect limits the laser melting process resolution because it causes the formation of discontinuous tracks [8], therefore limiting the formation of very sharp geometries. Moreover Surface roughness plays a vital role in the pitting corrosion in SS316L alloy which is widely used for biomedical applications [9-11]. Surface roughness is responsible for a non-uniform deposition of material on the previous layers, thus inducing a possible porosity and delamination between layers that is detrimental to the functional performance of parts, such as fatigue life for aerospace components and longevity for medical devices [5, 12]. There is limited research reporting on the experimental study on the surface roughness of laser melted parts. This study has firstly analyzed the surface morphology and roughness at various process parameters so as to optimize the process parameters for laser melted parts. Moreover this will improve the mechanical and corrosion behaviour of the laser melted parts.

2. Experimental details

Stainless steel AISI 316L with chemical composition weight percentage 0.03 C, 18 Cr, 14 Ni, 3 Mo, 0.75 Si, 2 Mn, 0.03 S, 0.10 N and remaining Fe was used as a substrate. The material of the substrate specimen of size ~ 50 × 40 × 3 mm is cut from stainless steel plate. These specimens were polished and grit blasted by sand blast (Grit 60) before laser melting. Commercial powder of SS 316L with average particle size of 20μm was used in this study. Initially, the stainless steel powder was spread over the substrate and maintaining the thickness of 100μm using scraper blade. Nd: YAG pulsed laser JK 300P (UK) was used for single track formation by varying the laser power, scanning speed and beam size. For conducting the experiments, taguchi L9 orthogonal array has been followed as shown in table 1. In addition Energy density of the laser beam is denoted by the equation [13].

$$E\rho = \frac{P}{vd}$$

Whereas P is the laser power used to scan a part; v is the scan speed or the velocity by which the laser beam moves over the powder surface, d is the spot diameter. For facilitating the quality of each condition of single line scanning, the scan track was observed by optical macroscopic analyzer. In addition, SEM was used to analyze the surface morphology and MAHR profilometer has been used to find out the surface roughness.

3. Results and Discussion

3.1. Surface morphology analysis

SEM analysis has been carried out for a number of different process parameters of the laser melted part. Figure.1 shows the profile of horizontal surface, normal to the build direction. The higher laser energy density produces (figure.1 (a-c)) fully melted, smooth and uniform layer. There are few spare, partially-sintered particles on the surface (figure.1(d)), which causes discontinuous layer and rough surfaces.

3.2. Surface Roughness

During laser melting process the surface roughness in the horizontal surface is generated by the rippling effect. When the laser travels from one point to another there is a temperature gradient between the laser beam and the solidifying zone, a shear force is generated on the liquid surface that is contrasted by surface tension forces [14-16] (Kamran and Neil, 2010; Dutta Majumdar et al., 2011),Ramos et al., 2003). However, due to quick melt pool solidification time, the relaxation process is often not fully achieved; instead a residual rippling on the surface is formed. However, it is possible to reduce the roughness generated by rippling effect, by surface remelting (Kruth et al., 2010; Fischer et al., 2003).

Experimental results show that the most important parameter that rule the surface roughness is the energy density [17]. On the other hand, the final surface roughness depends on the initial surface roughness [17], thus, the single track surface roughness studies help us to get the better understanding. Figure. 2 shows the mean roughness versus the energy density for the base line of the processed tracks. As in the figure 2 at the energy density between 2-4 j/mm^2 indicates a increases in surface roughness is noticed, this happens mainly due to the insignificant melt, input energy densities is not sufficient to melt the powder, thus the surface roughness also increased drastically. Moreover at higher energy densities the surface roughness is comparatively low. Figure. [3](a-i) shows the surface roughness at different energy densities. From the surface profile data (figure.3 (a)) at P 100 W; V 2.4 m/min; d 300 μm gives a maximum surface roughness. P 200 W; V 2.4 m/min; d 500 μm shows very minimum surface roughness and at figure.3 (g). From the surface profile data clearly shows that the laser parameter which produces continuous track gets reduction in surface roughness.

4. Conclusion

An investigation of surface roughness and morphology has been conducted for stainless steel 316L alloy parts made by laser melting process. The results clearly indicate that the continuous track produced by the laser attains reduction in surface roughness. In particular, SEM analysis confirmed the above statement. Laser parameters play a vital role in minimizing the surface roughness thus improving the mechanical as well as corrosion behaviour. Thus this study leads to obtain a maximum level of roughness reduction without any relevant errors and can be used to identify the optimal process parameters with minimum experimentation.

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Table 1. The selected process parameters for laser melting for making single layer track using taguchi L9 orthogonal array.

Trial No	Laser Power (W)	Laser Speed (m/min)	Beam Size (μm)	Energy Density (j/mm^2)
1	100	2.4	300	8.33
2	100	8.4	400	1.785
3	100	12	500	1
4	150	2.4	400	9.375
5	150	8.4	500	2.142
6	150	12	300	2.5
7	200	2.4	500	10
8	200	8.4	300	4.761
9	200	12	400	2.5

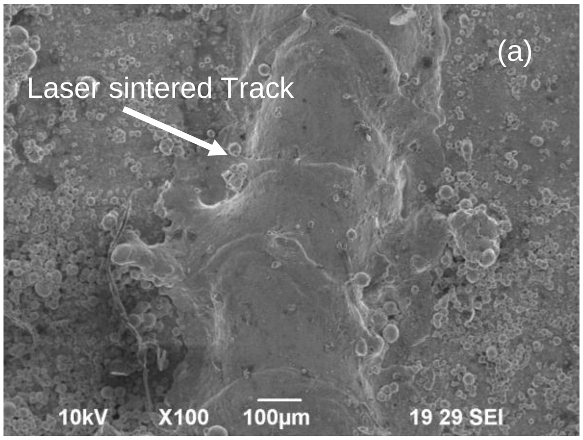

Figure.1(a)

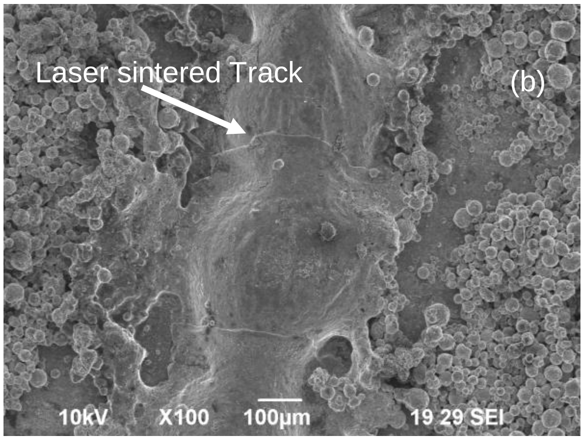

Figure.1(b)

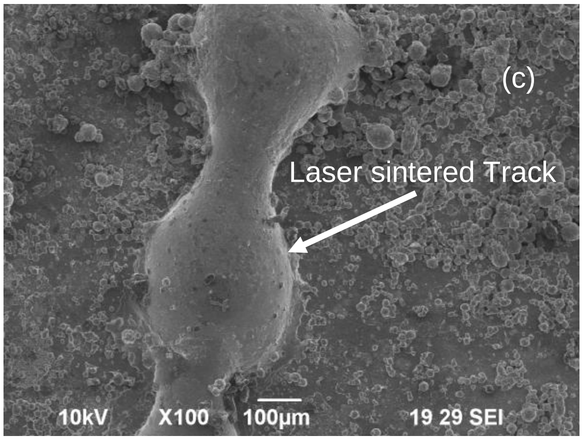

Figure.1(c)

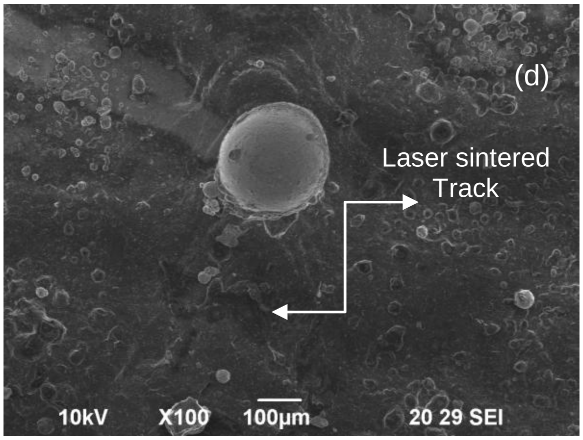

Figure.1(d)

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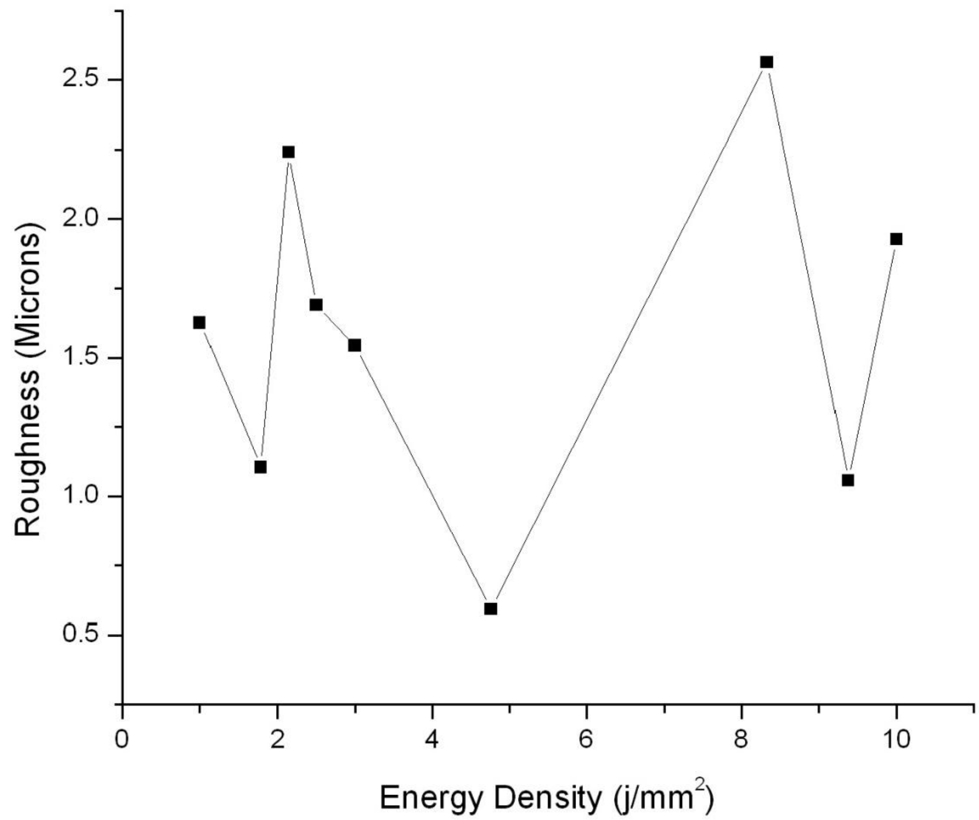

Figure.2

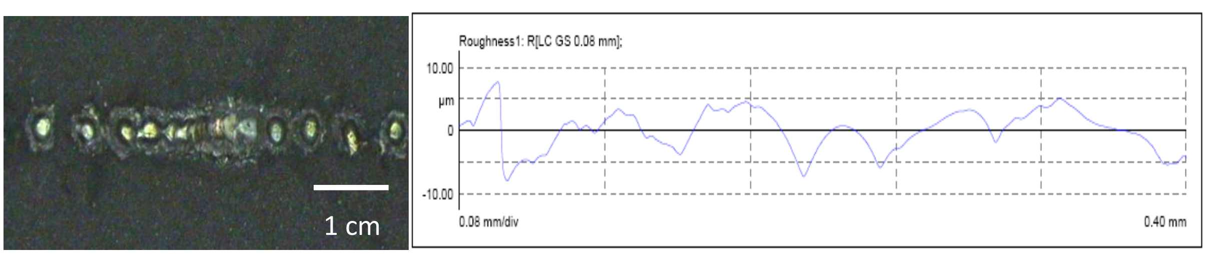

Figure.3(a)

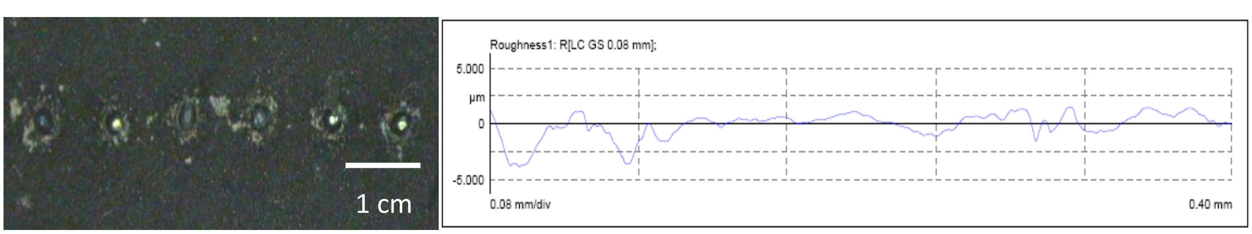

Figure.3(b)

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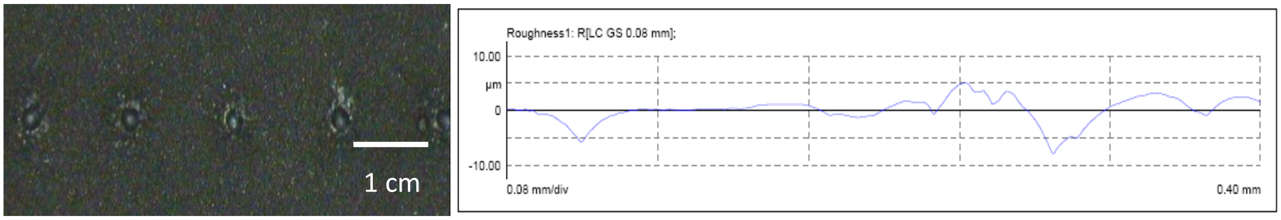

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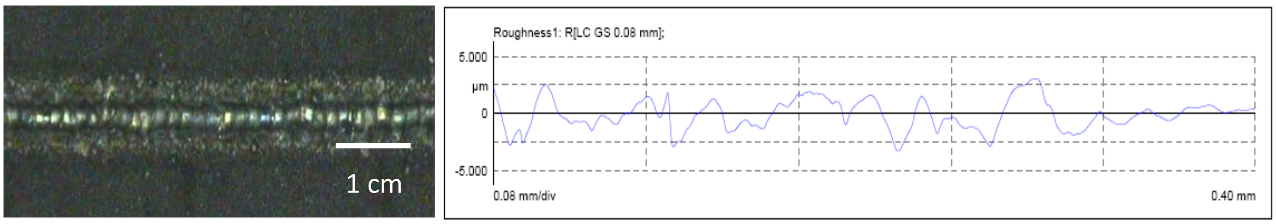

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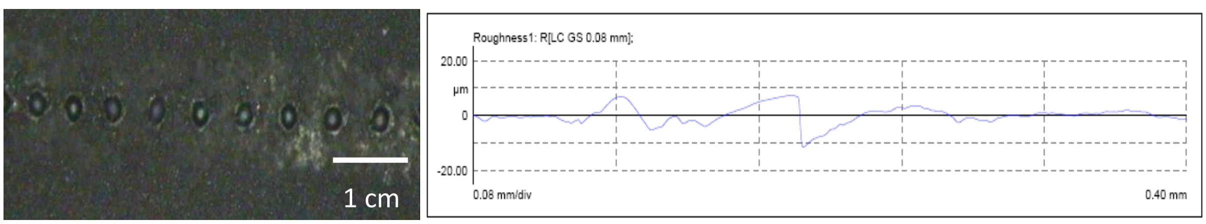

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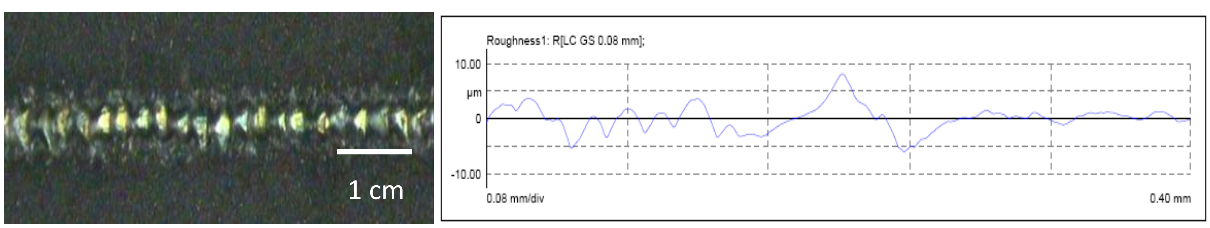

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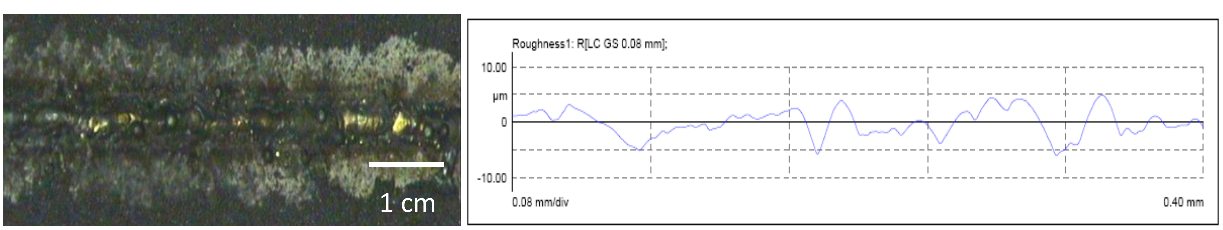

Figure.3(g)

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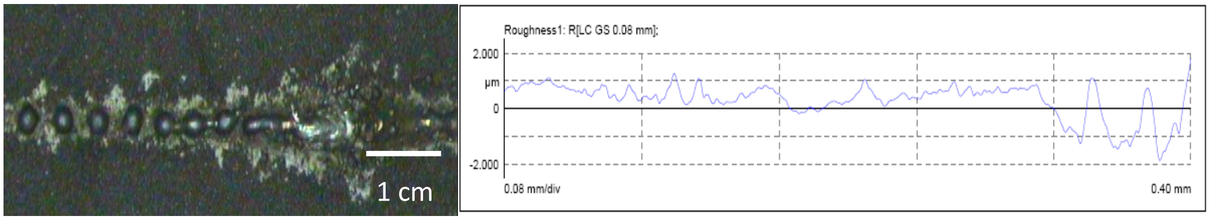

Figure.3(h)

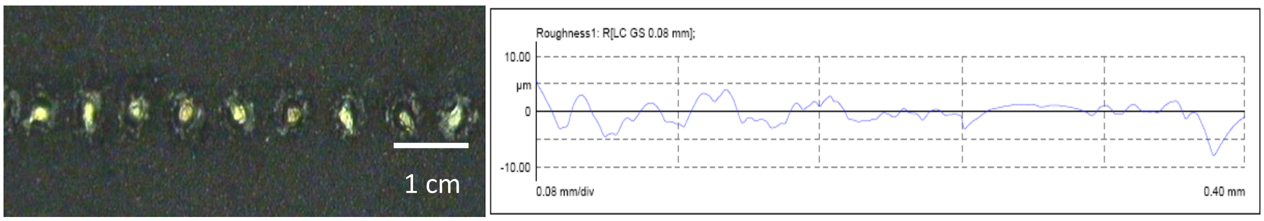

Figure.3(i)

Legends for Figures

Fig.1 (a) Laser power: 150 W; Laser Speed: 2.4 m/min; Beam Size: 400 µm
Fig.1 (b) Laser power: 150 W; Laser Speed: 12 m/min; Beam Size: 300 µm
Fig.1 (c) Laser power: 200 W; Laser Speed: 8.4 m/min; Beam Size: 300 µm
Fig.1 (d) Laser power: 100 W; Laser Speed: 12 m/min; Beam Size: 500 µm
Fig.2. Energy Density Vs Surface Roughness
Fig.3 (a) P 100 W; V 2.4 m/min; d 300 µm
Fig.3 (b) P 100 W; V 8.4 m/min; d 400 µm
Fig.3 (c) P 100 W; V 12 m/min; d 500 µm
Fig.3 (d) P 150 W; V 2.4 m/min; d 400 µm
Fig.3 (e) P 150 W; V 8.4 m/min; d 500 µm
Fig.3 (f) P 150 W; V 12 m/min; d 300 µm
Fig.3 (g) P 200 W; V 2.4 m/min; d 500 µm
Fig.3 (h) P 200 W; V 8.4 m/min; d 300 µm
Fig.3 (i) P 200 W; V 12 m/min; d 400 µm