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A Review on Layer Formation Studies in Selective Laser Melting of Steel Powders and Thin Wall Parts Using Pulse Shaping

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ABSTRACT

This paper advances the conclusions of the selective laser melting (SLM) of tool steel and stainless steel powders. The characteristic feature is the melting of single layers in deep powder beds by a continuous CO_2 laser. First, effect of development parameters on the surface roughness for each material is examined. Based on these results combined with visual observation of the solidified tracks, the question is then discussed as how the process ability of various type of steels is changed. Accordingly, Pulse shaping is a technique used to temporally distribute energy within a single laser pulse. This delivers to user an added degree of control over the heat delivered to the laser material communication zone. Pulses which makes a gradual heating or a stretched cooling effect can be produced with peak power/pulse energy combinations specifically tailored to control melt pool properties and eventual part formation. The results show that surface morphology of layers is affected strongly by scan spacing, thereby giving a lower normal roughness at compact scan spacing. The effect of scan speed is also amazing. This examination used a pulsed 550WNd: YAG laser to generate thin wall Inconel 625® parts using pulse shapes that delivered a variety of different energy distributions. Parts built with and without pulse figure control were measured for width, top and side surface roughness. The efficiency of pulse shaping regulator is discussed including potential benefits for use within the Selective Laser Melting process. Pulse shaping was shown to reduce spatter ejection during processing, advances the top surface roughness of parts and diminishes melt pool width.

Keywords: melting inconel, pulse shaping, ramp up, ramp down, selective laser

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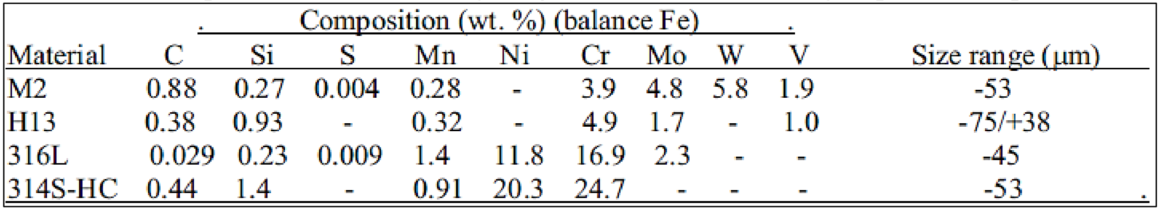
INTRODUCTION

Selective laser sintering (SLS) of metals has been the subject of scientific study and profitable expansions since the early 1990s, introducing significant findings in terms of process technology, systems, materials and application aspects [1–3]. Regarding the materials, however, only a limited number of commercial metallic powders have been already released and those materials also are limited to be used with the dedicated SLS machines for their best performance. This weakness may threaten the further successes of SLS process as a worldwide manufacturing technology. In this time Industry is becoming interested in Solid Freeform Fabrication (SFF) technologies to produce fully functional metal parts. This family of processes involves a layer-wise shaping and consolidation of material (e.g., powder and wire) allowing parts to be produced with a high geometric freedom directly from a CAD model. The use of SFF has also the potential to harshly reduce the time period between the primary conceptual design of a part and its actual fabrication. As a result, it is a need to broaden the range of used materials either by examining the conventional alloys, or, developing the new material systems. With focusing on standard ferrous alloy powders, this paper is an effort to this direction in which selective laser melting (SLM) of a number of selected steel powders is studied including A group of SFF technologies known as Direct Metal Laser Fabrication (DMLF) utilize lasers to consolidate metal. One such DMLF procedure known as Selective Laser Melting (SLM) builds metal parts by melting powder from a powder bed using a laser [4, 5].

EXPERIMENT

The experiments expected to examine the surface roughness of a number of certain steel powders at various process parameters. Gas atomized M2 high speed steel, H13 tool steel, 314SHC and 316L stainless steel powders were used in this study. 316L was selected because it has been found to be managed with relative ease. The composition and size fraction of the powders used are listed in Table 1. All tests were achieved using a research SLS machine built at the University of Leeds. After dispensation, layers were lifted from the bed, strongly brushed to remove loose powder, and weighed. Surface roughness perpendicular to the scanning direction (i.e. along the longer side of the layer) was measured with a Talysurf instrument, a contact surface profilometry, with a tip radius of 2.5µm. A cut off length of 2.5mm and a total evaluation length of 15mm was used. In addition to measuring the average roughness (Ra), different measures of roughness such as Rq, Rp, Rt and Rv were recorded to asses which might be correlated with surface feature [6, 7]. Very rough surfacing or the large holes that observed in the produced specimens at some experimental conditions, made the contact method of roughness testing impossible. Instead, a non-contact surface profiling system, Wykoo NT3300 optical profiler, was used to scan an area of 16×4mm in such cases [8].

Table 1. *Composition and size ranges of stainless, tool and high-speed steel powders.*



	Composition (wt. %) (balance Fe)									
Material	C	Si	S	Mn	Ni	Cr	Mo	W	V	Size range (µm)
M2	0.88	0.27	0.004	0.28	-	3.9	4.8	5.8	1.9	-53
H13	0.38	0.93	-	0.32	-	4.9	1.7	-	1.0	-75/+38
316L	0.029	0.23	0.009	1.4	11.8	16.9	2.3	-	-	-45
314S-HC	0.44	1.4	-	0.91	20.3	24.7	-	-	-	-53

The experiments also aimed to investigate Ramp Up and Ramp Down pulse shapes were used to produce thin wall parts. A total of 56 parts were produced, tested and compared to the properties of parts produced using a standard Rectangular pulse shape (non-shaped) developed in other work (Mumtaz and Hopkinson, 2009). It was envisioned that the use of pulse shaping would offer a more precise and tailored control over the heat input and would allow a refining and improvement over the use of standard Rectangular pulses [7–15].

Standard Rectangular Pulse (Non-pulse Shaped)

Figure 1 shows the standard Rectangular pulse shape used in producing a thin wall part (0.49mmin width) with low top (9_m) and side Ra (10_m) developed in other work (Mumtaz and Hopkinson, 2008). This pulse was produced without the use of pulse shaping and was used for comparison with parts produced using pulse shaping techniques. An image of the central portion of the top surface of the thin wall part is also displayed within the figure. The average peak power of this pulse was 1.4 kW, however the maximum peak power because of overshoot was 1.8 kW. It was observed that overshoot not only occurred with the pulse's power but also with the pulse's duration. Instead of being set on a minimum 0.5ms duration the pulse extends to 0.7 ms, this delay increases the heating time and potentially the volume of liquid produced and width of the part. During processing a plasma plume of approximately 5mm in height was produced from the processing area.

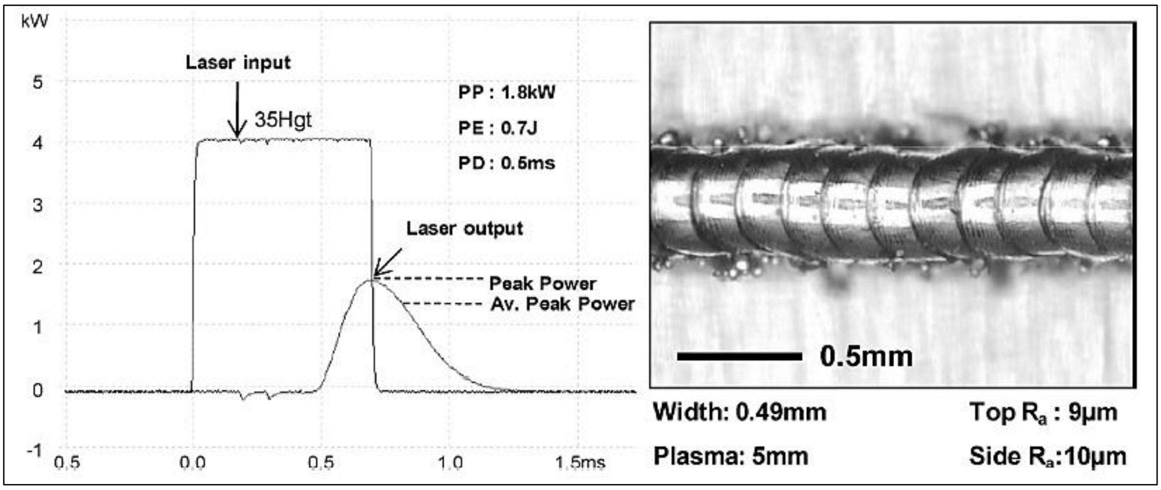


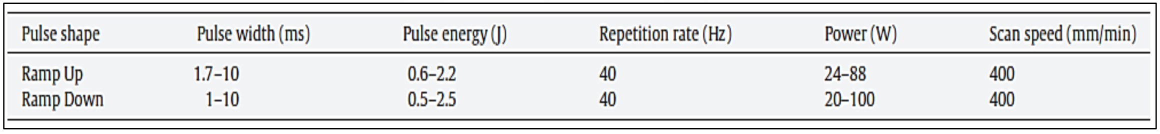
Fig. 1. *Optimized thin wall sample and standard rectangular pulse shape input and output.*

Ramp Up and Ramp Down Pulse Shapes Results

A diversity of Ramp Up and Ramp Down pulse shapes were produced and used to process four layers of Inconel 625®, each with a layer thickness of 100_m. The Ramp Up pulses varied from 1.7 to 10ms and contained pulse energies and peak powers ranging from 0.6 to 2.2 J and 0.7 to 1 kW, respectively. Note, it was not possible to produce Ramp Up pulses shorter than 1.7ms in duration due to the nature of pulsed laser generation creating an initial spike at the beginning of the pulse. This needed to be eliminated in order to allow gradual Ramp Up power delivery.

This was only achieved with extension of the pulse duration above 1.7 ms. Ramp Down pulses were easier to generate and varied between 1ms and 10ms and contained pulse energies and peak powers ranging from 0.5 to 2.5 J and 1.3 to 2 kW, respectively. The ranges of Ramp Up and Ramp Down parameters are shown in Table 2.

Table 2. *Ramp up/down pulse shape processing range.*



Pulse shape	Pulse width (ms)	Pulse energy (J)	Repetition rate (Hz)	Power (W)	Scan speed (mm/min)
Ramp Up	1.7–10	0.6–2.2	40	24–88	400
Ramp Down	1–10	0.5–2.5	40	20–100	400

Due to the energy distribution within a ramped up pulse shape, melt pool generation is more likely to occur at the end of the pulse when peak power is at its highest. Leading up to the main peak power the gradual increase in laser energy heats up the material and reduces its reflectivity, allowing energy to be more easily absorbed. As a result of this energy distribution the peak power required to melt Inconel 625® was on average 0.8kWless than that used within the ramped down pulse shapes [16, 17].

RESULTS AND DISCUSSION

Reduced Scan Spacing

Figure 2(a) reveals the effect of scan speed on the measured average roughness, Ra, of 316L stainless steel processed at scan spacing of 0.06 mm (90% beam overlap). The results show that the roughest surface is produced at the lowest scan speed. This is due to the fact that the high delivered energy to the powder bed at low level of speed forms an enlarged molten pool, thereby increasing the surface roughness.

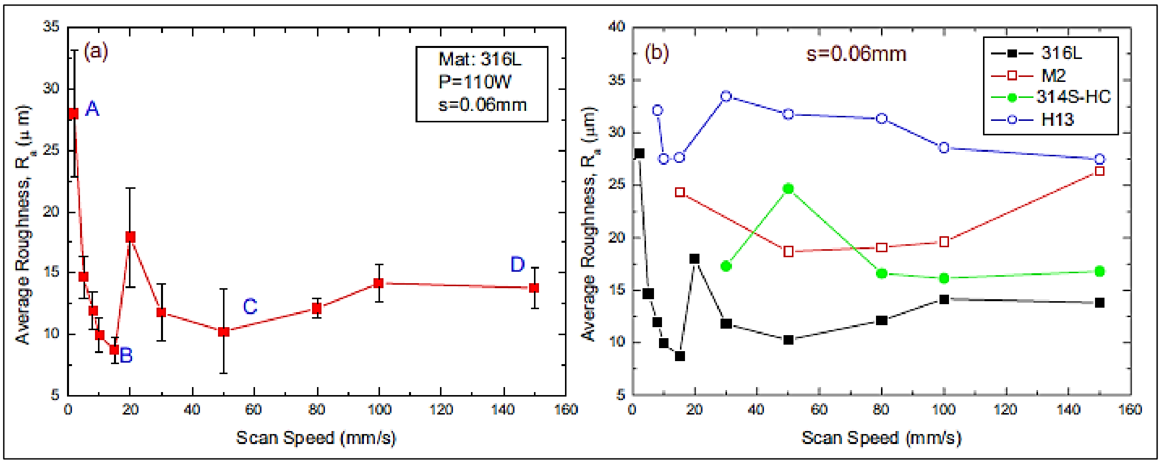


Fig. 2. *Measured average roughness at s=0.06mm, (a) 316L, (b) all batch of powders.*

Moderate Scan Spacing

The calculated average roughness of the samples as a function of scan speed, for the scan spacing of 0.30 mm, are shown in Figure 3(a). At this scan spacing, full dense layers were formed at a lower speed level, thereby performing the surface texture testing from a speed of 2 mm/s. The highest Ra was recorded for M2 when processed at 2mm/s. For all the powder batches, Ra is affected by speed in a similar way.

Increased Scan Spacing

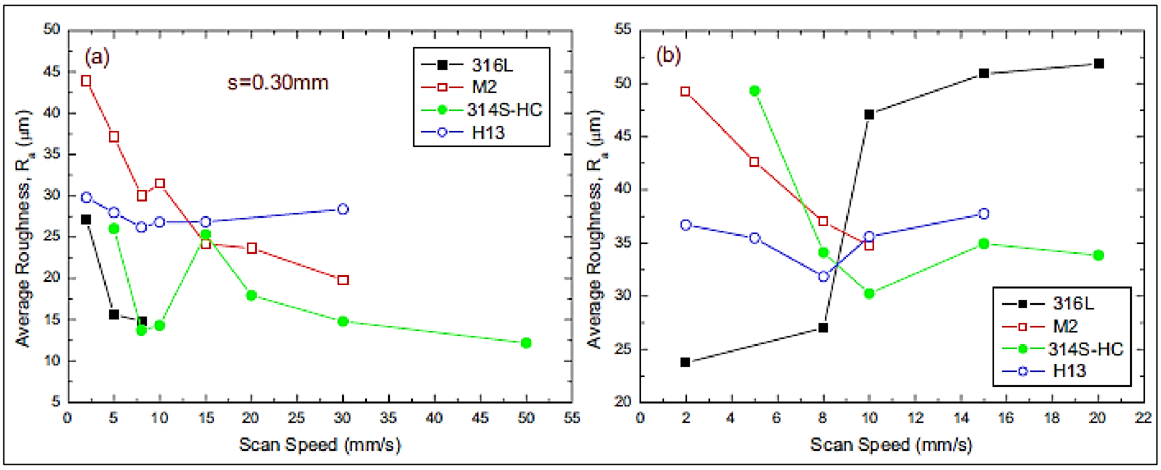


Fig. 3. *Measured average roughness for all powders, (a) s=0.30mm, (b) s=0.60mm.*

Figure 4 shows the results of surface Ra and width of the thin wall structures made using the different pulse shapes.

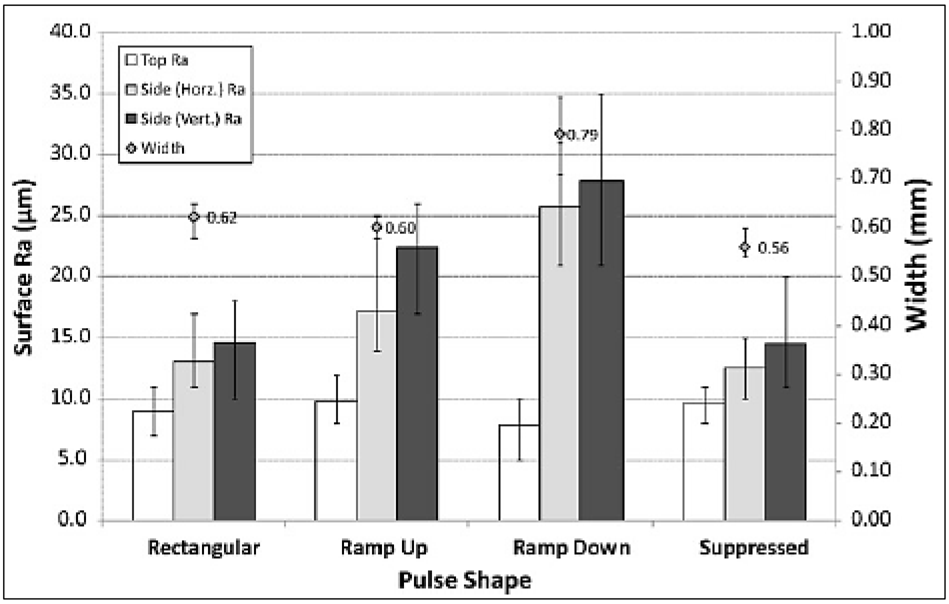


Fig. 4. *Thin wall part surface roughness and width.*

Rectangular Pulse

The rectangular pulse produced thin walls (0.62±0.04 mm in width) with a top Ra values (9±2_m) as expected, lower than that of side Ra (13±4_m horizontal and 15±5_m vertical). It was discovered that the side Ra in the vertical direction was higher than that of the side Ra in the horizontal direction. This could be a result of interlayer connections between melted layers of growing powder Ra in this direction.

Ramp Up Pulse

It is particularly useful in minimizing plasma plume/spatter generation during processing. This pulse used the same pulse energy as that of the rectangular pulse.

Ramp Down Pulse

The ramp down pulse had been identified in Section 3.2 as the pulse that would produce parts with the lowest top Ra. This pulse had the same peak power as the Rectangular pulse but contained a higher pulse energy of 1.1 J spread over a longer duration.

Suppressed Pulse

The Suppressed pulse was able to minimize the laser on-time down to 0.5 ms. The pulse was also designed to hold a high peak power, low energy and short duration. Results indicate that the thin wall structure produced had a low top and side Ra (10±2_mtop, 12±3_mhorizontal and 15±6_m vertical) that were very similar to those produced with the rectangular pulse [15, 18, 19].

CONCLUSIONS

Selective laser melting of 316L and 314S stainless, M2 high speed and H13 tool steels was investigated. Single layers were produced on loose powder bed. The findings can be summarized as follow:

(1) Surface morphology of layers is affected strongly by scan spacing.
(2) Excessive heat input at low speed ranges, as well as instability of molten tracks at higher speeds give rise to porosity.
(3) A reduced scan spacing and higher scan speed led to lower average roughness for all the powder batches examined in this study.
(4) Roughness parameters Rp, Rt, Rsk, and Rku were found to be useful tools for evaluation of laser melted surfaces.
(5) M2 high speed steel was found to have the most random surface, i.e., the lowest repeatability.

(6) Ramp Up pulse shapes generally operated at lower peak powers as compared to standard and Ramp Down pulses. this reduced the peak power required to induce full melting.
(7) The gradual heating could be viewed as preheating reducing spatter generation during processing.
(8) Ramping up is not effective in reducing top/side Ra due to slow melt pool generation and use of low peak powers.
(9) The external mechanical force applied by recoil pressures was also a factor in flattening and smoothing the top surface profile of the melt. This gave more time for heat to conduct from the melt pool into the surrounding powder.
(10) A Suppressed pulse shape that consisted of a high peak power, low energy and abbreviated time duration proved to be the most effective pulse shape.
(11) This improved the wetting of the melt pool onto the substrate within a short space of time and flattened out the top surface profile of the melt pool.

Because of the short laser on-time and low pulse energy the width of the melt pool is reduced due to less energy and less time for heat to diffuse sideways causing a narrowing of the melt region and preventing satellite formation.

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