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Effect of process parameters on the surface topography formation in precision additive metal manufacturing

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Abstract

The typical surface topography of parts produced by additive manufacturing differs from those produced by conventional manufacturing. During the powder bed fusion process, spatter particles may eject from the melt pool due to multi-physics phenomena. These spatter particles can have an impact on the part quality as large spatter particles that land on the top of the powder layer may shield the powder from the laser beam, resulting in lack of fusion porosity and increases surface roughness. The measurement of spatter is important to understand the process and to predict the performance of parts. In this study, the effect of laser power and scan speed on the surface topography of the top surface of Maraging steel grade 300 is investigated. The parts were produced by an in-house powder bed fusion machine LM-Q with a powder size distribution of 15 µm to 45 µm. A surface topography comparison was made between several samples which were produced by different process parameters regarding laser power and laser speed, leading to different Archimedes' densities. The surface topography was measured by a confocal microscope. The topography data were pre-processed with bi-cubic interpolation and least square plane subtraction. For the parameter evaluation, S- and F-filters with appropriate nesting index settings were used. Several conventional and surface texture parameters are evaluated in order to investigate the correlation with the production parameters.

Keywords: Surface texture parameters, Surface topography, Precision additive metal manufacturing

1. Introduction

The surface quality of additive manufactured (AM) components depends on the quality of the previous layer, therefore the surface quality of each intermediate layer determines the quality of final part [1, 2]. Various topographical features e.g. spatters or melt pool ripples are formed on the AM surface by complex physical interactions. These features are present as the signatures of the AM process [3]. Quantitative measurements of these features can provide useful information to optimise AM process parameters, e.g. energy density and/or normalized enthalpy [4]. This work briefly presents the relationship between AM process parameters and surface topography of Maraging steel grade 300.

2. Experimental methods

An in-house developed AM machine of KU Leuven (LM-Q) was used to build the AM parts. This machine is equipped with a fibre laser with a wavelength of 1080 nm and a maximum output power of 1 kW. The focused laser beam has a spot diameter (d_{spot}) of 50 µm ($\O_{1/e^2}$) on the building plane. AM parts (10 mm x 10 mm x 5 mm) were built with different process parameters from Maraging steel (18Ni300) powder having a particle size range of 15 µm to 45 µm. The layer thickness (t) used was 30 µm. The hatch spacing (h) was 80 µm and the scan strategy was bi-directional with the contour first and with + 90° rotation between subsequent layers.

2.1. Process parameters

The process parameters selected to manufacture the parts are shown in Figure 1. The purpose of using different process parameters was to study the effect of laser power and scan speed on Archimedes' relative density and surface texture parameters.

The linear energy density (LED), normalized enthalpy (NE) and theoretical productivity (TP) were calculated by using the following equations:

$$\text{Linear Energy Density} = \frac{P}{v} \tag{1}$$

$$\text{Normalized Enthalpy} = \frac{\Delta H}{h_s} = \frac{A \cdot P}{\pi \cdot h_s \cdot \sqrt{D \cdot v \cdot d_{spot}^3}} \tag{2}$$

$$\text{Theoretical Productivity} = v \cdot h \cdot t \tag{3}$$

Where P is the laser power (in W), v is scan speed (in mm/s), d_{spot} is the spot diameter (in mm), h is the hatch spacing (in mm) and t is the layer thickness (in mm). The thermo-physical properties of Maraging steel used to calculate normalized enthalpy are absorptivity A = 0.35, density ρ = 8000 kg/m^3, specific heat capacity c_p = 450 J/kg · K, melting temperature T_m = 1703 K, thermal diffusivity D = 4.17 x 10^{-6} and enthalpy at melting h_s = 6.13 x 10^9 J/m^3 [5].

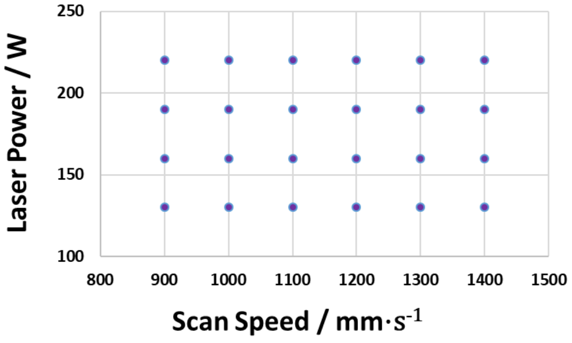

Figure 1. Process parameters used for Maraging steel grade 300.

2.2. Measurement of Surface topography

A 2.5-D optical confocal microscope (S neox - Sensofar) was used to measure the top surfaces of the AM parts. A stitched area of 8.33 mm x 7.26 mm was measured with a pixel size of 1.3 µm using a 10x objective, NA = 0.3. After measurement, the topography was pre-processed by removing spike-like artefacts and subtracting the least-squares plane. The surface was filtered using a Gaussian filter characterized by a S-nesting index of 8 µm and a L-nesting index of 150 µm. The cut-off wavelength was chosen according to the minimum feature size e.g. spatter particles (~ 10 µm) and the maximum feature size e.g. melt pool track width (~150 µm) [7]. From these topography data, surface texture parameters were calculated by using the surface metrology software MountainsMap® from DigitalSurf. Watershed segmentation with 5% *Sz* height pruning was used. A scanning electron microscope (SEM) XL30 FEI at 500× magnification in secondary electron mode was used.

3. Results and discussion

Surface texture parameters were calculated according to ISO 25178-2 [6]. We investigated the amplitude parameter *Sq* and the hybrid parameter *Sdq* because these are more independent surface texture parameters. Table 1 shows the surface texture parameters (*Sq* and *Sdq*) and the AM process parameters laser power, scan speed, linear energy density (LED), normalized enthalpy (NE), theoretical productivity (TP) and the obtained Archimedes' relative density (D) for Maraging steel grade 300. Archimedes' relative density was measured to correlate bulk part quality to surface quality. The linear energy density (LED) and normalized enthalpy (NE) are highest for high laser power and lower scan speed. There is always a compromise between productivity (TP) and bulk density (D), as can be seen in Table 1. Also, there is an obvious relation between linear energy density (LED) and Archimedes' relative density (D). A higher bulk density was achieved with higher linear energy density (Table 1).

Table 1 AM process parameters, relative density and surface texture parameters for Maraging steel grade 300.

#	**Laser power**	**Scan speed**	**LED**	**NE**	**TP**	**D**	***Sq***	***Sdq***
Unit	**W**	**mm/s**	**J/m**	**unitless**	**mm^3/s**	**%**	**µm**	**°**
1	130	900	144.44	3.45	2.16	98.75	14.20	0.95
2	160	900	177.78	4.25	2.16	98.98	10.05	0.81
3	190	900	211.11	5.05	2.16	99.10	6.95	0.61
4	220	900	244.44	5.84	2.16	99.08	7.79	0.70
5	130	1000	130.00	3.28	2.4	98.28	15.40	1.02
6	160	1000	160.00	4.03	2.4	99.06	13.07	1.02
7	190	1000	190.00	4.79	2.4	98.92	10.75	0.82
8	220	1000	220.00	5.54	2.4	98.86	10.20	0.80
9	130	1100	118.18	3.12	2.64	97.44	16.96	1.06
10	160	1100	145.45	3.84	2.64	98.90	14.91	1.03
11	190	1100	172.73	4.56	2.64	98.98	14.13	1.00
12	220	1100	200.00	5.28	2.64	98.96	8.99	0.73
13	130	1200	108.33	2.99	2.88	96.16	17.42	1.07
14	160	1200	133.33	3.68	2.88	98.76	16.91	1.07
15	190	1200	158.33	4.37	2.88	98.96	14.75	1.04
16	220	1200	183.33	5.06	2.88	98.98	12.65	0.93
17	130	1300	100.00	2.87	3.12	95.05	16.68	1.01
18	160	1300	123.08	3.54	3.12	98.39	17.51	1.10
19	190	1300	146.15	4.20	3.12	98.88	16.14	1.04
20	220	1300	169.23	4.86	3.12	98.94	15.17	0.95
21	130	1400	92.86	2.77	3.36	93.26	16.56	0.96
22	160	1400	114.29	3.41	3.36	97.83	17.46	1.03
23	190	1400	135.71	4.05	3.36	98.70	17.62	1.13
24	220	1400	157.14	4.68	3.36	98.86	17.87	1.08

Table 1 shows a lower *Sq* and *Sdq* value for high power than for low power while using a similar scan speed. This can be explained by assuming that when the laser power increases, the melt pool size also increases [8]. With larger melt pools, more re-melting of previous layers occurs, which results in a smoother surface. However, if we exceed the laser power above a certain limit, additional defects may be introduced, such as keyhole porosity [9]. On the other hand, when the scan speed is increased, the melt pool size breaks down due to high surface tension, so the surface roughness can be expected to increase. Figure 2 shows the continuous melt pool and cold spatter on surface of the sample #3 having the highest relative density of 99.10% and the discontinuous melt pool and hot spatters on surface of sample #21 that has the lowest relative density of 93.26%.

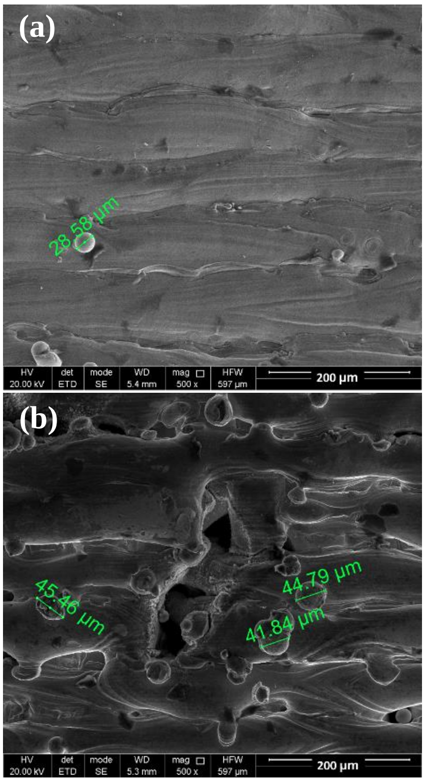

Figure 2. SEM images of top surface of sample (a) #3 and (b) #21.

4. Conclusion and future work

The quantitative relationship between the mechanisms that contribute to surface topography and process parameters was investigated. A lower *Sq* value was observed for samples produced with high power. Characterising the signature features of AM surfaces such as spatters helps to establish a link between AM surface topography and its production mechanism. The future work will be the implementation of surface topography measurement techniques for the further optimisation of AM processes and also the functional performance of AM final parts.

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