INFLUENCE OF POWDER PARTICLE SIZE DISTRIBUTIONS ON SURFACE TOPOGRAPHY OF POLYMER LASER POWDER BED FUSION PARTS

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Abstract

The morphology and particle size distribution of commercial polymer powders for Laser based Powder Bed Fusion (PBF-LB) spans a wide range. This is a consequence of the traditional manufacturing methods of milling and grinding. In theory, a combination of large and fine powder particles provides dense powder packing which in turn allows for good processability and parts. This study focuses on correlating powder properties and part quality for parts manufactured with 3 different size distributions, i.e. commercial grade, narrower than commercial, and a mix of different size spans. Parts were made with polyamide-11 and the results indicate a more suitable particle size distribution for a specific material and a specific machine. Hence spending some additional resources on sieving powder prior to use can be beneficial. However, an optimization should be carried out for each powder and material to find the ideal powder size distribution corresponding to desired part quality.

Introduction

Laser based powder bed fusion for polymer (PBF-LB/P) is one of the older Additive Manufacturing (AM) processes which is still largely popular and has very recently been seen entering into the consumer space of products [1]. However, consumer products are not an easy market since with functionality also comes the need to have aesthetics and haptics. The Airless Gen1 basketball from Wilson© , went through multiple stages of post-processing just to be able to satisfy that requirement [1]. This is due to the fact that PBF-LB/P can not produce 'smooth' surfaces like injection molded parts, and hence the need for post-processing of the parts beyond the usual unpacking of the powders from the bed is required. Multiple post-processing stages are value adding processes and will raise the cost of the final products. Most studies into improving surface quality focus on laser process parameters [2], [3] and few into other factors like final layer powder spreading [4] and powder particle properties[5]–[7]. Some of the previous works cover the aspect of size and shape distribution affecting the powder packing density which in-turn affects the final part quality [5]–[7]. Hence the goal of this work is to look at the powder material properties like size distribution to define its influence on surface quality.

Powders available on the market are of multiple materials, shapes (due to production type) and size distributions. This work focused on one material and one machine and investigating three different types of particle size distributions to check for the influence. Where one is the commercial powder, one is narrower powder particle size distribution (PSD) and the other is a mix of large and fine particles. It is known that a high fraction of fine powders are characteristic of the powders made from mechanical methods such as cryogenic milling [7]. These can be beneficial in providing an improved packing density [8] but cause poor powder spreading [9]. This work uses such a powder hence a focus towards types of PSDs which can be created from an off-the-shelf commercial material has been selected.

Methodology

Polyamide 11 (PA11) powder, PA1101 from EOS GmbH was the powder material used for this experimental work. All experiments were carried out using virgin powder. For sieving of powders, test sieves of size Ø 200 mm x 50 mm and vibratory shaker AS 200 Control from Retsch were used. The test sieves used had the mesh sizes of 25 µm, 45 µm, 63 µm, and 90 µm. Based on the guide from Retsch [10] and a couple of iterations, the optimal sieving parameters were chosen while also taking into account the agglomeration of powder particles and the blocking of the sieve mesh. For each round of sieving 125-150 gm (1 scoop) of powder was loaded into the sieving stack and sieved for 5 minutes at an amplitude of 1,3 mm and an interval of 1 sec each. The powder particles sieved from each size span was used to make two of the three powder batches used for the experiments, illustrated in FIGURE 1. The three powder batches used for the experiments are referred to as Commercial (as received from supplier), Narrow (45 µm – 65 µm after sieving), Mix (25 µm – 45 µm & 63 µm – 90 µm mixed after sieving). The powders were mixed in a ratio of 25% and 75 % respectively based on the amount of powder sieved and inspired from research carried out by Sohn et al, [11]. To verify the PSD after sieving, 3 x 10 ml samples from each size span was characterized using dynamic imaging analysis on a QICPIC RODOS/L VIBRI/L by Sympatec GmbH. The used powder from the 3 batches were characterized for their PSD as well.

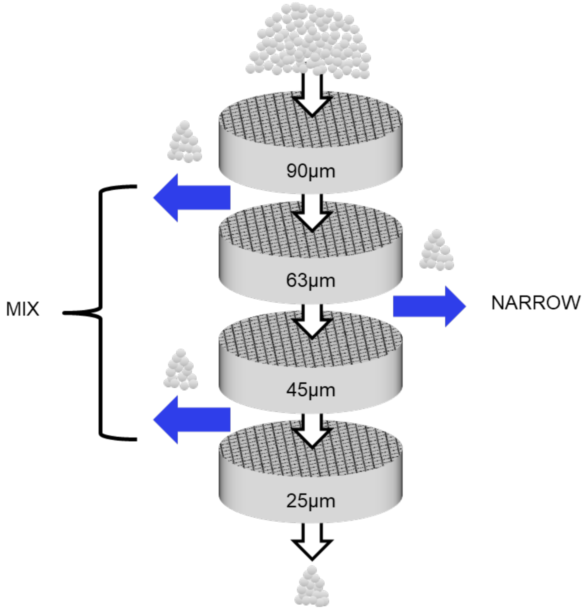

FIGURE 1 Sieving of powders for producing batches for experimentation

The parts manufactured from each batch consisted of 14 parts for surface characterization. All the parts were spread across the build area to get a representative value of the properties, as seen in FIGURE 2. The process parameters used were the standard parameters with settings for 4 layers of Upskin and Downskin settings, which translates to a scan speed of 6000 mm/s, laser power of 12,5 W, and a hatch distance of 0,12 mm. The parts were manufactured on a Formiga P 110 Velocis, with a layer thickness of 40 µm. All manufactured parts were media blasted in a Powershot C from DyeMansion GmbH after unpacking for 8 min.

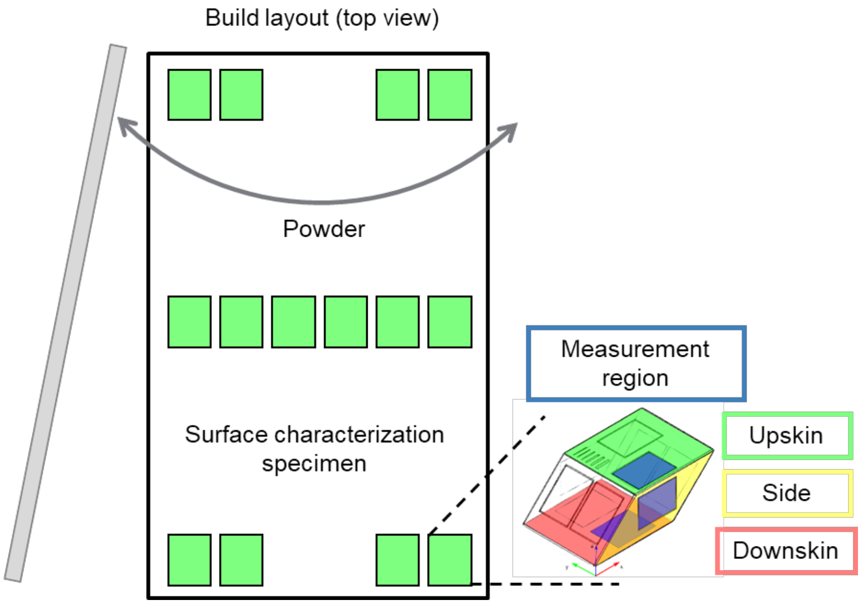

FIGURE 2 *Build layout for manufacture of surface characterization parts*

The surface characterization was carried out using a non-contact 3D optical profiler Neox S from Sensofar Metrology. The characterization was carried out in confocal fusion mode [12]. As seen in FIGURE 3 a 6x7 stitched scan of area 4,22 mm x 4,10mm (width x height) with 20% overlapping was carried out using a 20x objective that has a pixel size of 0,69 µm. The surface topography data was analysed using MountainsMap 10 from Digital Surf. A 2nd order form removal was carried out before quantifying the surface topography in terms of areal surface parameters as per ISO 25178-2. All parts were rested for 48 hours prior and measured in a controlled environment of 20 ± 1 °C and 50 ± 5 % relative humidity.

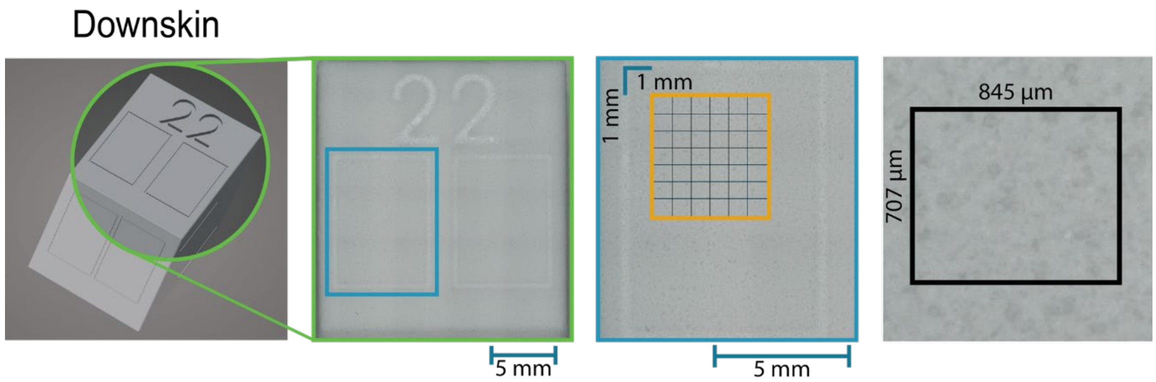

FIGURE 3 *Illustration of surface measurement methodology for each part*

Results & Discussion

The particle size distribution (PSD) of the powders from each cut-off after sieving is shown in FIGURE 4. The histogram in terms of counts (per sample) shows an effective sieving of large powder particles for mesh sizes ≥ 45 µm. However, a significant number of fine particles (< 20 µm) exists in all the cut-offs. The most plausible reasoning for this is the shape of the powder particles. Most have sharp features and significant surface asperities which leads to high degree of mechanical locking. Since the process used is dependent on separation of individual particles by fluidization and gravity based sieving, failure to undo agglomeration due to mechanical locking will result in poor sieving outputs.

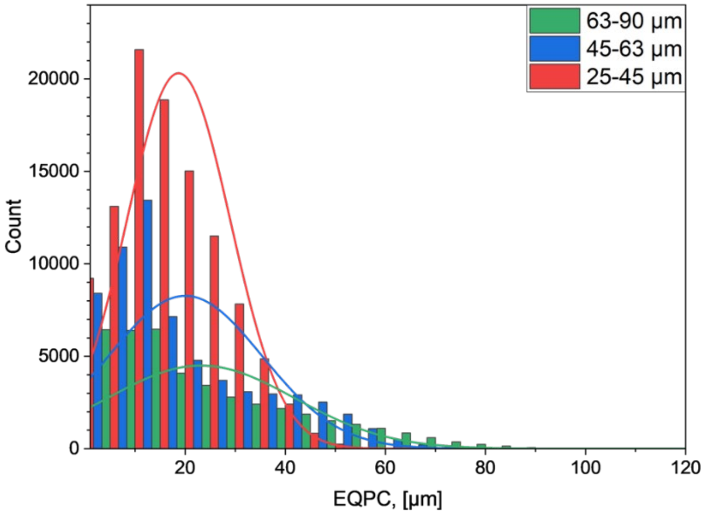

FIGURE 4 Resultant PSD for sieved powder

The particle size distribution for the final powder batches is displayed in FIGURE 5 (a). As mentioned, the number of fine particles are significantly high and that is visible in the final powder batches as well. Due to a failure in building specimens using the Narrow powder batch the first time and the lack of additional powder, parts were made by using Commercial powder for the buffer layers and Narrow for the rest. The 'new' Narrow powder batch's PSD is shown in FIGURE 5 (a), traces of powders greater than 63 μm are observed, however they are less than that of the Commercial and Mix powder. PSD of the used powder is show in FIGURE 5 (b). A decrease in the number of fine particles is noticed for all the powders, a result of increased fine particle adhesion during the process.

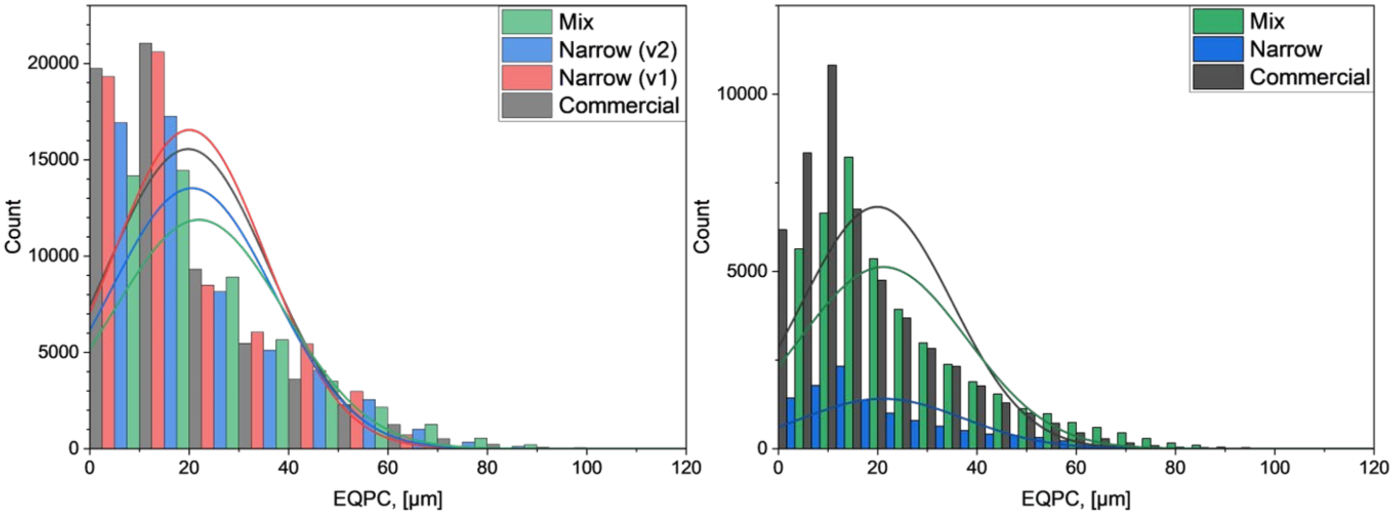

FIGURE 5 (a) PSD of virgin powder batches (b) PSD of used powder batches

The surface roughness of the parts represented by *Sq* (root mean square) is shown in FIGURE 6. The results indicate a decrease in mean *Sq* for Narrow and Mix powder batches. There is also a reduction in the variance of the *Sq* values for the parts made using Narrow and Mix. However, these indications of a correlation between particle size and surface topography don't follow the same trend on all faces. The difference in mean *Sq* is larger for Side faces (> 1 μm) as compared to the other faces (0,5 – 1 μm). Literature shows that the surface roughness of Upskin also depends on the interaction of the powder with the melted zone underneath [4] and the assumption is that the same can be said for the rest of the part; i.e the surface topography is not only dependent on the powder properties and process parameters but also the interaction of packed powders with the melted regions. Hence the results were checked for the parameter *Sdr* (developed interfacial area ratio), which would give an indication if the degree of texture of surface has increased or decreased.

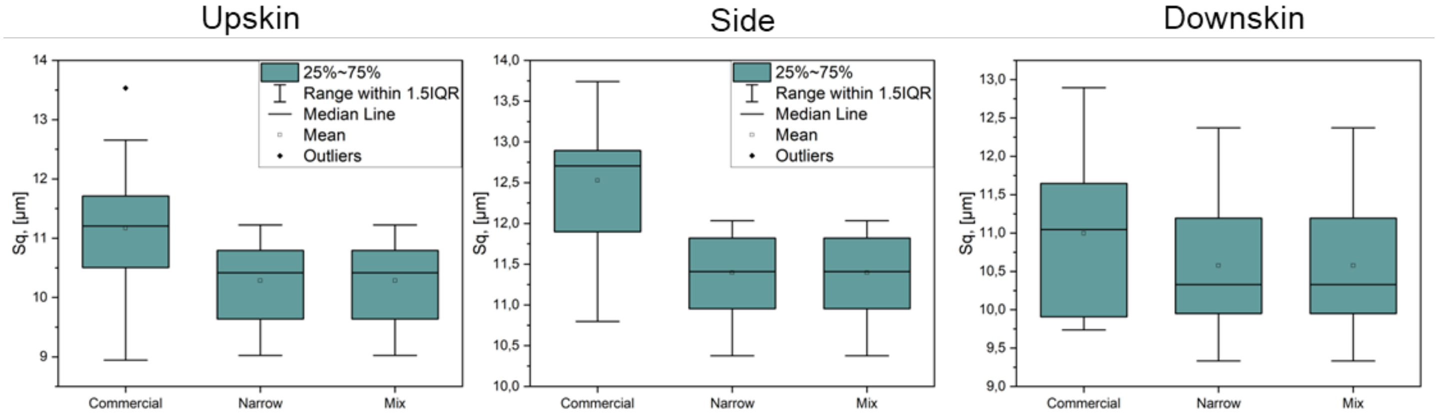

FIGURE 6 Comparison of surface parameter Sq across batches on different faces

The *Sdr* values for parts from different batches is shown in FIGURE 7. The mean *Sdr* values indicate a clear reduction of approx. 5% for both Narrow and Mix vs Commercial. This result is more reliable compared to those from *Sq* since the difference in mean values was quite small. There is a large variance in the values which is due to the non-homogeneity of surface topographies produced by the process. Hence it can be said that the surface roughness is reduced when using powders with a narrower PSD and a mix of large and fine particles. The improvement in surface quality need not always be indicated by single parameters like *Sq* but instead a combination of surface parameters should be explored based on the existing knowledge about the surface to define the best parameters for the investigation, like in this case *Sdr*.

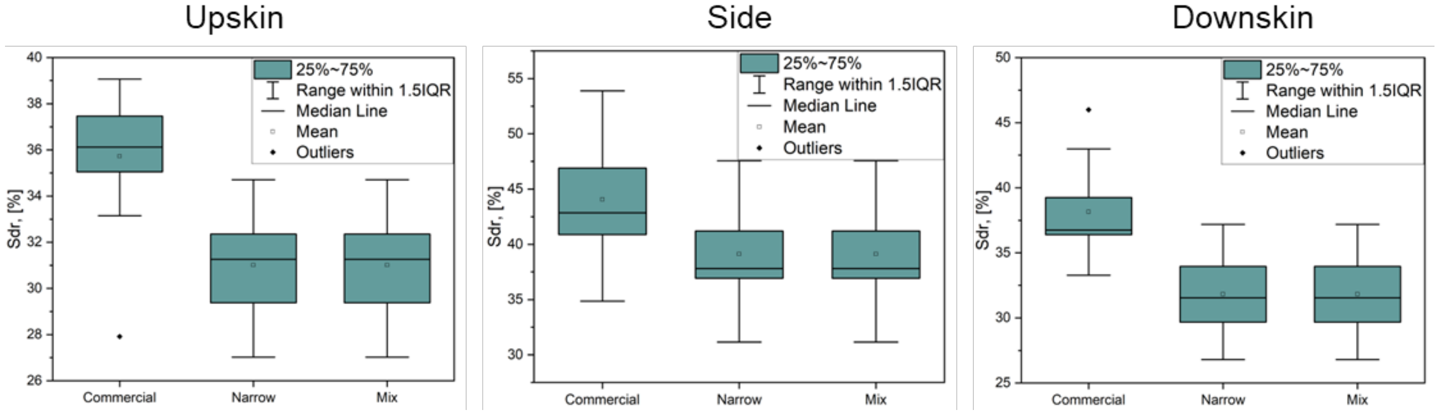

FIGURE 7 Comparison of surface texture parameter Sdr across batches on different faces

The experiments were carried out on a commercial system with one of the best resolutions for PBF-LB/P at the time and hence it is quite substantial that slight effort in tailoring the PSD has a positive effect on surface quality. Even though the work highlights this connection it lacks to show the influence of the material's melt properties, assuming that process parameters are optimized by the manufacturer. Even though the PSD helps improve the surface quality, without mapping out all the powder properties (size, shape, flow, spread, melt, etc) it is difficult to define which property would have the most significant influence on surface quality. Previous research has shown that a narrow PSD influences the flow and spread, which in turn improves the packing density and hence the surface quality [5]. But another work which explore the mix of PSDs indicates that surface roughness is dependent of the size and shape of the particles [6]. Hence it is essential to look at current findings as a work in progress.

Conclusions & Future scope

The current work helps broaden the understanding on the factors affecting the surface topography of parts produced by PBF-LB/P. It is highlighted that a tailored PSD:

1. Narrow PSD – 20 µm around the layer height,
2. Mix PSD – A combination of large and fine particles (ratio based on empirical data),

can reduce the surface texture of parts manufactured by the process. There are small reductions in the *Sq* (~ 1 µm) and a slightly more significant reduction in *Sdr* (~ 5%).

Since this work focuses purely on surface quality the next steps would be to cover the impact of PSD on the mechanical properties of the parts and an investigation into the use of virgin & reused powder. As sieving is an added processing step it is essential to check if it is feasible for different materials as well. Based on these further investigations it would be useful to define if an added step of tailored powder PSD is beneficial in specific use cases or something that the industry should strive towards.

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