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Effect of build platform location and part orientation on dimensional accuracy of down-facing surfaces in LPBF

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Abstract

Additive Manufacturing (AM) technologies are creating pathways for a digital transition in manufacturing and the Laser Powder Bed Fusion (LPBF) process remains the most promising and successful technology in this regard. This has inspired research and development efforts to further capabilities and to push the state of the art in order to open up even more applications. Down-facing features are one of the most critical features within all LPBF parts and this work presents an investigation on the effects of build platform location and part orientation on the dimensional accuracy of printed part. This work makes evident that the pressure of gas flow and direction do play a role on the final quality of down-facing surfaces. Orienting down-facing surfaces parallel to the gas flow gives the best dimensional accuracy. While parts furthest away from the gas flow nozzles presented the least dimensional accuracy. This work also allows the future development of compensation strategies for printing parameters based on the location of the down-facing surface on the build platform as well as for considering other responses such as density, surface roughness etc.

Keywords: Laser Powder Bed Fusion, Location, Dimensional accuracy, Orientation, Down-facing surface.

1. Introduction

Additive Manufacturing (AM) technologies are helping facilitate a transition of the manufacturing ecosystem [1, 2]. From one dominated by conventional processes such as milling, drilling or welding, towards digital manufacturing processes in tune with Industry 4.0 visions such as digital twinning, functional designs, decentralised production etc. [3]. This has driven research and development efforts within AM to grow drastically in the recent past in order to push capabilities, quality and new applications [4].

The Laser Powder Bed Fusion (LPBF) process (see Fig.1) is one of the most popular Metal AM processes and has seen large amounts of Industrial adoption as well as academic research [5, 6]. This is mainly due to its capacity to produce a large number of materials with excellent mechanical properties, while offering other benefits such as improved lead times, high part density and has allowed the creation of complex parts with improved functionalities and in comparison to other metal AM processes has lower changeover times, better accuracy and capability of printing fine powders (10 µm d50) thereby making it suitable for micromanufacturing applications. [7].

However, due to the complexity of the laser-material interactions and the large number of process parameters, there is still progress to be made in achieving a repeatable and predictable process [8].

The dimensional accuracy of parts produced by LPBF are affected by a variety of reasons [9]. One of the primary reasons being that due to the layer by layer nature of the production, there is constant heating up to melting followed by cooling of the material in each layer [10]. This repeated process causes shrinkages and warping of components [11]. Down-facing surfaces suffer the additional issue of inefficient heat transfer away from the powder bed, caused due to the absence of solid material [12]. Lose powder has poor thermal conductivity, which then causes overheating within the down-facing area which might also cause the meltpool to transition to a keyhole melting mode [13]. This causes large dross formations, which are large artefacts containing excess melted material that is attached to the component. These dross formations cause high surface roughness and large dimensional deviations [14].

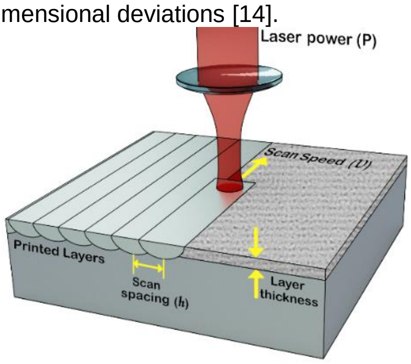

Fig. 1. A schematic of the LPBF process

In previous work, the authors have investigated the relationship between laser parameters and determined that the most significant are laser power and scan speed [15]. However, it is the expectation of the authors, supported by few recently reported work, that the position on the build plate and orientation of the part w.r.t the direction of gas flow also plays a role on the obtained dimensional accuracy of the down-facing surfaces.

The effect of build platform location has been the subject of investigation in previous research works. Veetil et al. investigated this for stainless steel 316 L parts made by LPBF and reported that the deviation of samples in the direction perpendicular to the gas flow is larger than the deviation parallel to the gas flow. This observation was attributed to the pressure of the gas flow as well as the location on the build platform [16]. Most LPBF systems contain a gas flow system that blows perpendicular to the direction of the recoater mechanism. The main function of the gas flow is to remove any emissions that might arise from the meltpool and to draw them towards the exhaust ports.

Although there have been a number of recent studies attempt to examine the effect of part location and orientation on different process responses, there still a large margin to elucidate the phenomenon further. In this context, the aim of the current work is to investigate this phenomenon for Ti6Al4V, for applicability within down-facing surfaces. The surface quality within down-facing surfaces is already dependant on the rheology of the meltpool within that region, and it is expected that the gas flow directly impacts the rheology of the meltpool. The degree to which the down-facing surfaces are impacted based on their location and 2 different orientations is discussed.

2. Materials and Methods

2.1. *Materials*

The material used in this study is the Titanium alloy TI6Al4V obtained under the brand name LaserForm Ti Gr23 (A) which is highly suitable for aerospace and bio-medical applications due to its light weight, high strength and optimal mechanical properties. The chemical composition of the LaserForm Ti Gr23 (A) alloy is seen in Table 1.

Table 1. Chemical composition of LaserForm Ti Gr23 (A) alloy

Element	% of Weight
Ti	Balance
N	≤0.03
C	≤0.08
H	≤0.012
Fe	≤0.25
O	≤0.13
Al	5.5 – 6.5
V	3.5 – 4.5
Y	≤0.005
Residuals (total)	≤0.4

2.2. *Test Pieces*

Test pieces with down-facing surface inclined at an angle of 35° were designed using CAD software (SolidEdge ST9). The inclined angle is relative to the build platform as can be seen in Fig 2.

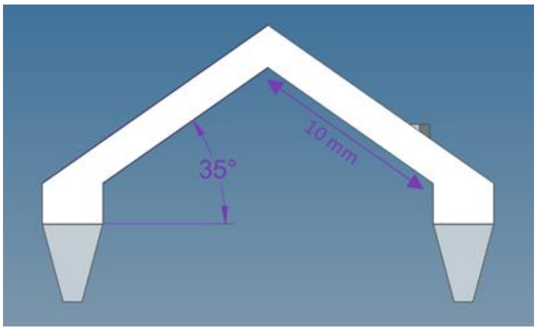

Fig. 2. Front view of designed test pieces

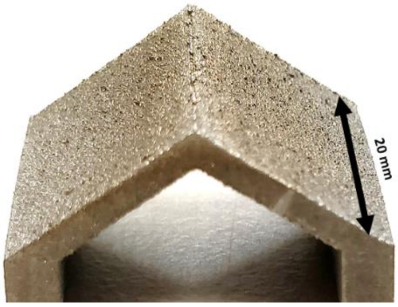

Fig. 3. 3D printed test piece

2.3. *LPBF Processing*

The test pieces were manufactured on a 3D Systems DMP 320 LPBF system with standard printing parameters for the bulk and with down-facing parameters as seen in the Table 2. The down-facing parameters were selected based on previous research and experience on the system, as developed optimal process parameters.

Table 2. Process Parameters used within the down-facing area

Process Parameter	Value
Laser Power	150 W
Scan Speed	800 mm/s
Scan Spacing	60 µm
Layer Thickness	60 µm

All test pieces were printed with the same process parameters and the only variation within test pieces are the locations on the build platform for both respective angles. There were a total of 2 repetitions made over 2 print jobs, where the complete print were repeated with identical parameters and location of test pieces, this was done to have a good confidence on the repeatability of the samples.

2.4. *Experimental Methodology*

In order to test the effect of the location, the build platform was split into a three by three grid, as can be seen in Fig 3. The grey squares depict the top view of the test pieces as they were oriented. Each grid contained two test pieces, one of which was oriented parallel to the gas flow and one of which was oriented perpendicular to the gas flow.

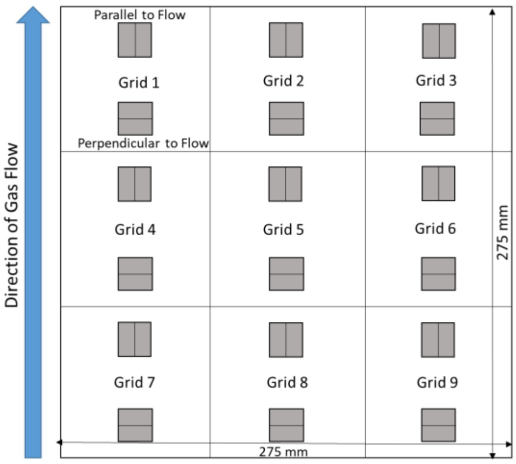

Fig. 4. Depiction of Experimental Methodology and position of samples on the build platform grids.

2.5. Measurement

All test pieces were measured using a Keyence VHX 7000 4K digital Microscope (Keyence Ltd). The measurement for the dimensional deviation was measured at the thickness of the walls. The walls have a thickness dimension of 1.72 mm for all test pieces, and since all the test pieces were printed with identical process parameters, the only influence on the final dimensional accuracy is the impact of the location on the build platform and the part orientation.

The dimensional deviation of each sample is calculated through the difference between the measured value of the thickness and the intended value of the thickness based on the CAD design.

3. Results and Discussion

3.1. Dimensional accuracy at each grid location.

The average dimensional error as a result of each individual location is seen below in Fig 4.

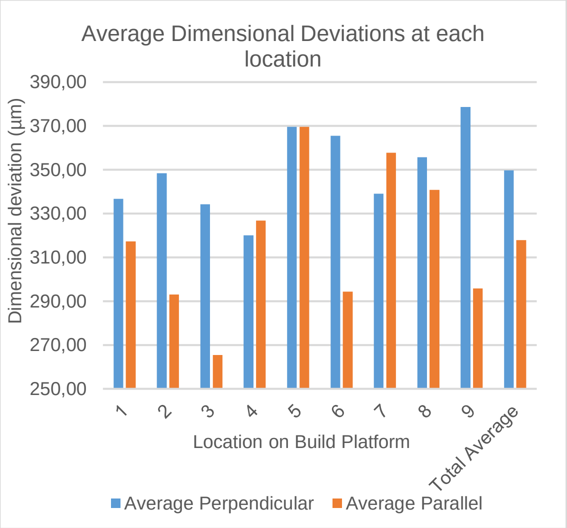

Fig. 5. Dimensional deviation of each test piece at different grid locations

Some observations can be made from observing the individual deviations in each location.

- In average the dimensional accuracy of parts oriented parallel to the gas flow is better than those oriented perpendicularly as they display lesser deviation from the CAD design.
- There seems to be some larger correlation and patterns emerging over the whole build platform such as how the deviation in positions 3, 6 and 9 are always minimal, therefore it is worth investigating the phenomenon by allocating zones as follows in the grid.
- It is seen that all the samples have a nominal thickness greater than the design thickness. This is an expected phenomenon due to excess melting that will always take place in unsupported overhang regions.

3.2. Dimensional accuracy at different zones

The grid structure is split into three rows and three columns in order to investigate the deviation over the whole zones. The nine different zones can be seen in Fig 5. The columnar zones are seen in orange and the row based zones are depicted in green.

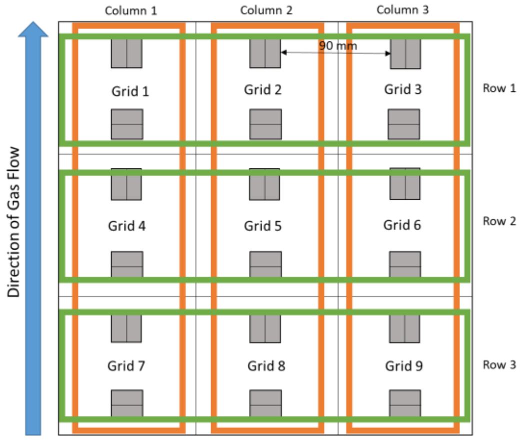

Fig. 6. The 6 different zones allocated in the build platform

The averaged dimensional error for each of these zones can be seen in Fig. 6

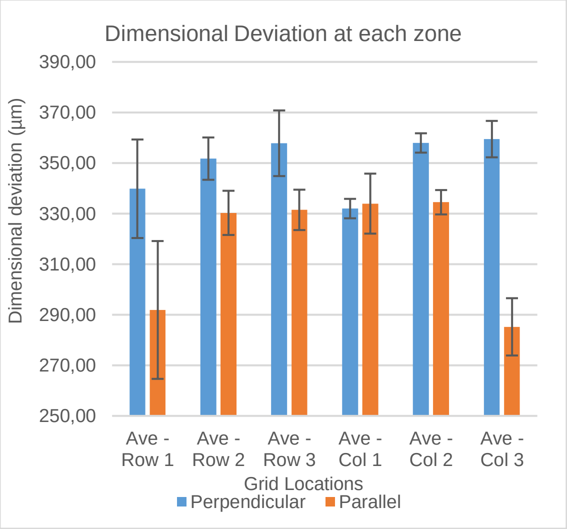

Fig. 7. Dimensional deviation within each zone.

- It is seen that largely, perpendicularly oriented samples have a higher dimensional deviation than that of the parallel oriented samples. The authors hypothesise that this might be due to the directional cooling effect of the gas flow. Secondly, the gas flow impacts a parallel oriented surface for a longer duration than a perpendicularly oriented surface, and therefore this is a chance of removing more material from the parallel surface which can cause its lower dimensional deviation, as in down-facing surfaces a higher material removal will mean a more accurate surface.
- It is seen that for both the perpendicular and the parallel samples, the deviations in Row 1 are the least. This is the row that is the farthest away from the gas nozzles. While for Row 2 and Row 3, the deviations were almost identical. The row that is farthest away from the door and the window has the least deviation, therefore that authors hypothesise that this might be caused by atmospheric reasons.
- While for the columnar, it is seen that for the

perpendicularly oriented, the Column 1 has the least deviation, whole for the parallel orientation, the deviation is least in Column 3. The authors attribute this to the pressure of the gas flow and how it interacts with each oriented sample. There might be slight differences in the gas flow pressure along different columnar zones within the build platform, which affect the way that cooling and as a results solidification takes places along different orientations.

4. Conclusions

This study provides evidence that there is a systematic effect on dimensional accuracy, based on the position as well as orientation of samples. Dimensional accuracy of down-facing surfaces can also be linked to the direction of flow, the pressure and the location of the down-facing surface in different zones. Conclusions that can be made are:

- Down-facing surfaces that are oriented parallel to the gas flow display lesser dimensional deviations when compared to surfaces that are oriented perpendicular to the gas flow.
- The direction of the gas flow might affect the cooling rate of the surfaces which directly affects the dimensional deviation, therefore this is a parameter to consider when planning builds.
- The gas flow might cause more material removal in parallel oriented samples, which resulted in better dimensional accuracy for down-facing surfaces.
- For the parallel oriented samples showed best accuracy in Row 1 and Column 3. While the perpendicular samples showed best accuracy in Row 1 and Column 1.
- Row 1 is the farthest set of samples from the door and window of the build area, and therefore this might be as a result of atmospheric efforts.

The paper presents a good starting point to understand the effects of location and orientation on the quality of down-facing surfaces. This effect might have further impact on other properties such as surface roughness, part density, mechanical strength etc. Therefore, it will be focus of future research works. This work also furthers understanding of down-facing surfaces, and can contribute towards generating compensation parameters for printing of accurate down-facing areas.

5. Acknowledgements

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