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Contact-free support structures effect on dimensional deviation of LPBF printed components with overhang features

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Abstract

Laser powder bed fusion (LPBF) process has gained great attention in recent years since it enables the production of very complex parts with acceptable dimensional accuracy, cost and mechanical properties. Since LPBF process is a thermal process and very high thermal stresses occur during production, dimensional deviations occur especially in very thin and overhang regions. The aim of this study is to show the feasibility of using contactless supports at thin and overhang regions for reducing dimensional deviation of the final part. For this purpose, 1.5 mm thick overhang parts with 30^0 inclination angles with respect to build plate were manufactured with LPBF process from In718 material. Contactless supports with different amount of gaps between the overhang surface and the support (0.23, 0.31 and 0.38 mm) were used during production. The produced parts were 3D scanned with a blue light device. Experimental results showed that 0.23 mm support gap showed the lowest amount of dimensional deviation (0.007 mm) and increasing support gap increased the dimensional inaccuracy. Moreover, surface irregularities such as adhesion of non-fully melted particles were observed on overhang surfaces which increases when support gap increases.

Keywords: Dimensional deviation, contact-free support, laser powder bed fusion

1. Introduction

Laser powder bed fusion (LPBF) method is a sub-branch of powder bed fusion additive manufacturing (AM) processes where laser energy is used as the energy source to melt the metal powder laid on a build platform with a recoater blade. With the vertical movement of the build plate, the part is produced layer by layer according to the machine specific tool path based on 3D computer aided design (CAD) file sliced in a virtual environment [1]. When laser energy scans the powder particles, a molten metal pool called melt pool is formed. Due to gravity effect, some non-fully melted particles may integrate to the melt pool causing high surface roughness and dimensional deviation issues [2]. Based on surface inclinations of the part and process parameters, especially energy density (density based on laser power, laser scanning speed, hatching spacing and layer thickness), the amount of non-fully melted particles adhesion can change [3]. Moreover, during production, high amount of thermal stresses occur resulting in dimensional variations in especially thin and overhang areas. To solve this problem, supports can be added to these areas which serve as an anchorage to the build platform. However, these support structures need to be removed after production since they are not a part of the final component. Contact-free supports where there is no direct contact between the support and the overhang surface seems to be a good alternative to solid supports to eliminate the need for machining of the support structures after production. In contact-free supports, the gap between the support and the overhang surface is a key factor that affects the producibility of the final component. For lower values of gap distances, there is a risk of fusion of contact-free support structures on the overhang surface. Then, extra time and cost are needed to remove the support from the main part after printing. On the other hand, if higher values of gap distances are used, then contact-free support structure may not provide enough heat dissipation which results in melt pool sagging and higher dimensional deviation [4]. Smaller gaps reduce the part distortion, but they increase the risk of melting/sintering of metal powders in the gap especially when the melt pool is deeper than the gap [5]. Therefore, it is very important to use the proper contact-free support gaps for obtaining the final component with minimum amount of distortion. Zhang et al. investigated three different support gaps (0.3, 0.45 and 0.75 mm) in LPBF produced overhang parts and stated that 0.3 mm support gap showed the minimum distortion [6]. Apart from LPBF method, contact-free support structures were also used in electron powder bed fusion (EPBF) method, another powder bed fusion method which uses electron energy to melt the powders. In these studies, 0.21 mm [7, 8], 0.49 mm, 0.63

mm and 0.77 mm [9] support gaps were used, and it was stated that support gap has a direct influence on distortion and dimensional deviation of the overhang parts.

In this study, the effect of contact-free support gap on dimensional variation of LPBF produced In718 parts was investigated. Produced parts were scanned and obtained data was compared with the original CAD geometry. Microstructural characterization was also performed to better understand the distortion and dimensional deviation behavior.

2. Material and methods

LPBF enables the manufacturing of thin-walled specimens. Therefore, in the present study, 1.52 mm thick, thin-walled specimens were used. It is well known that any overhang regions making less than 45° with respect to build plate need to be supported. To use contact-free support structures effectively, specimens making 30° angle with respect to build plate were used in this study. The specimens were modelled using Siemens NX software (Fig. 1). Contact-free supports with three different gaps (0.23, 0.31 and 0.38 mm) were used to support the overhang surfaces (Fig. 2). Concept Laser M2 LPBF machine was used for the production of the specimens from In718 material. During production 50 µm layer thickness, 160 W laser power, 800 mm/s laser scan speed for skin, and 680 mm/s laser scan speed for core, 80 µm laser spot size for skin and 53 µm laser spot size for core were used. For each of the support gaps, three specimens and total of 9 specimens were manufactured. After production, supports and the final parts were removed from the build platform with GF Agiecharmilles wire electrical discharge machine. Specimens were scanned with ATOS ScanBox 4105 blue light device and GOM Inspect software was used to evaluate the dimensional deviations of the produced specimens from the original CAD geometry. The specimens were cut at thin-walled sections with Struers Secotom cutter, mounted in Struers CitoPress mounting machine and polished with Struers Tegramin. These parts were then inspected in Nikon Eclipse MA200 optical microscope for metallographic studies.

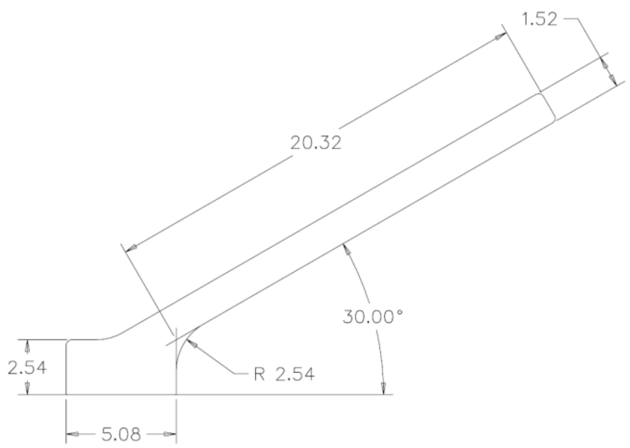

Fig 1. Thin-walled specimen used in the present study

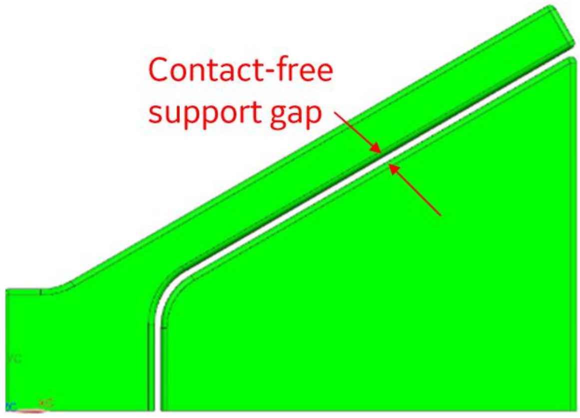

Fig 2. Contact free support and gap

3. Results and discussion

Fig. 3 shows the downfacing surfaces of produced specimens. High surface roughness was obvious in all specimens. The surface roughness values were measured in our previous study, and it was observed that specimens 1-3 showed 49.99 µm, 63.51 µm and 64.97 µm average surface roughness values, respectively [10]. The results showed that increasing the support gap increased the surface roughness.

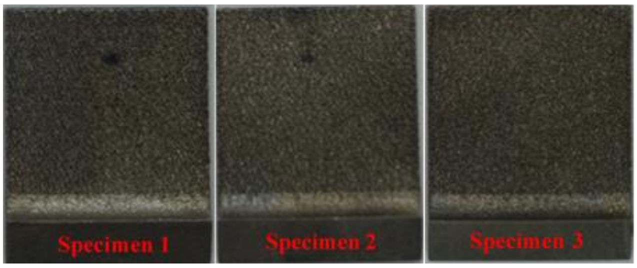

Fig 3. Downfacing surfaces of produced specimens

Fig. 4 shows the average thickness deviation with respect to support gaps. It is clear that increasing support gap resulted in an increase in average thickness deviation. The minimum (0.0073 mm) and the maximum (0.0418 mm) average thickness deviations were observed at 0.23 mm and 0.38 mm support gaps, respectively. When support gap increased from 0.23 mm to 0.31 mm and from 0.31 mm to 0.38 mm, average thickness deviation increased by 216% and 81%, respectively.

When support gaps increase, the heat dissipation behavior between contact-free support and the specimen changes. At increased support gaps, molten melt pool tends to move towards the powder bed underneath. This causes more fused particles attached to the downfacing surface which increase the dimensional variations. Fig. 5 to Fig. 7 shows optical microscope images of specimens supported by contact-free supports with 0.23 mm, 0.31 mm and 0.38 mm support gaps, respectively. It is clear from these figures that some non-fully melted particles are attached to the surface and the amount of these particles increases with an increase in support gaps. Between mating surfaces of fused particles and the specimen, columnar grains were

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observed. Moreover, some microcracks and porosities were also observed in the specimens which decrease the mechanical strength and fatigue life of the specimen.

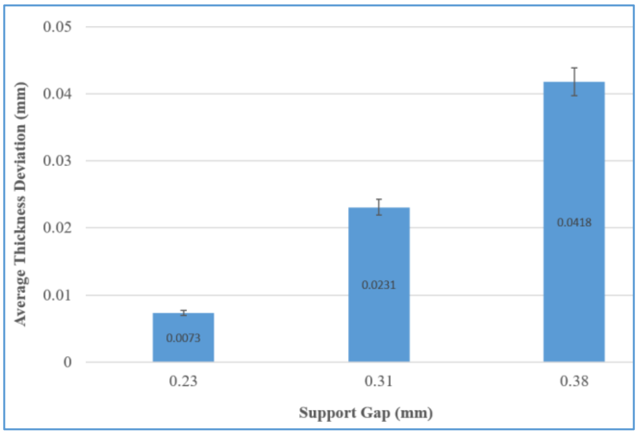

Fig 4. Average thickness deviation of specimens supported by contact-free supports with different support gaps

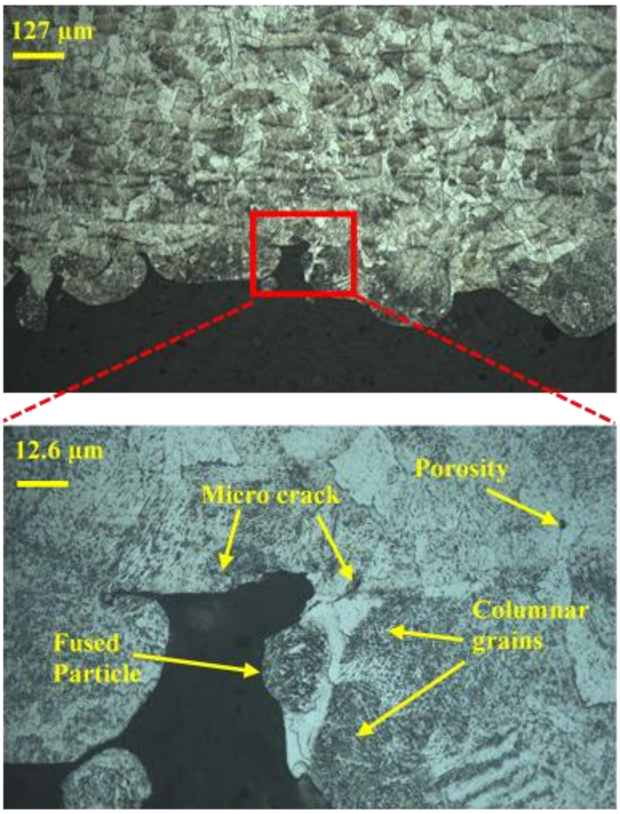

Fig 5. Optical microscope image of specimen 1 with 0.23 mm support gap.

Fig. 8 shows bluelight measurement results of upfacing and downfacing surfaces of specimens. For all specimens, downfacing surfaces showed higher distortions than upfacing surfaces. Since there is no direct contact between contact-free supports and the specimens, melt pool penetrates towards the powder bed with different amounts in different regions of downskin surfaces. On the other hand, upfacing surfaces is supported by the previous layers, therefore, a smoother distortion and deviation were observed. It is also clear from Fig. 8 that the tip of the specimen showed the highest distortion due to the free edge effect of the tip when compared to the root of the specimens which make solid connection to the baseplate.

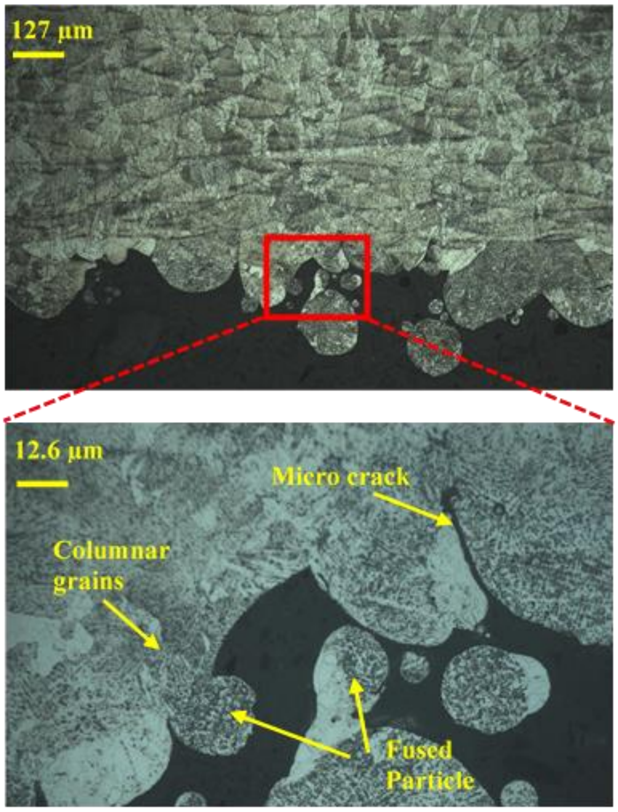

Fig 6. Optical microscope image of specimen 2 with 0.31 mm support gap.

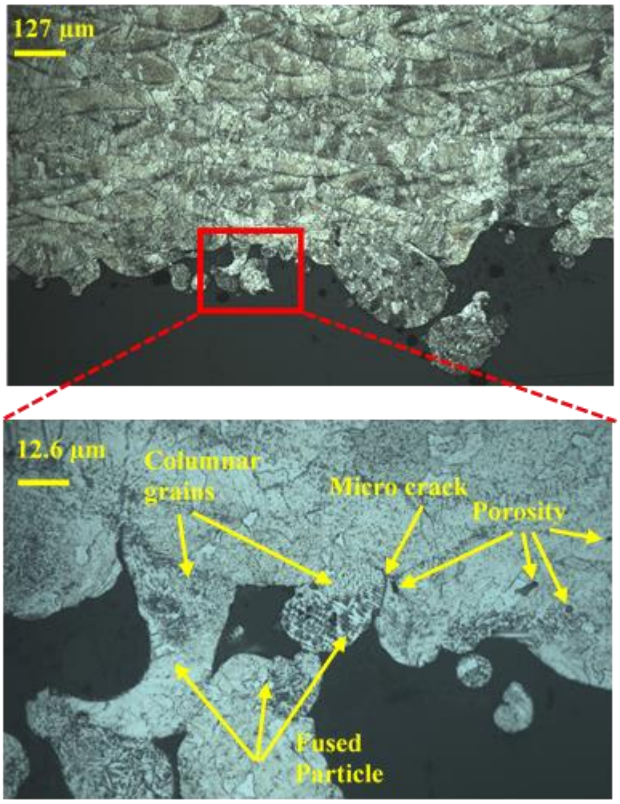

Fig 7. Optical microscope image of specimen 3 with 0.38 mm support gap.

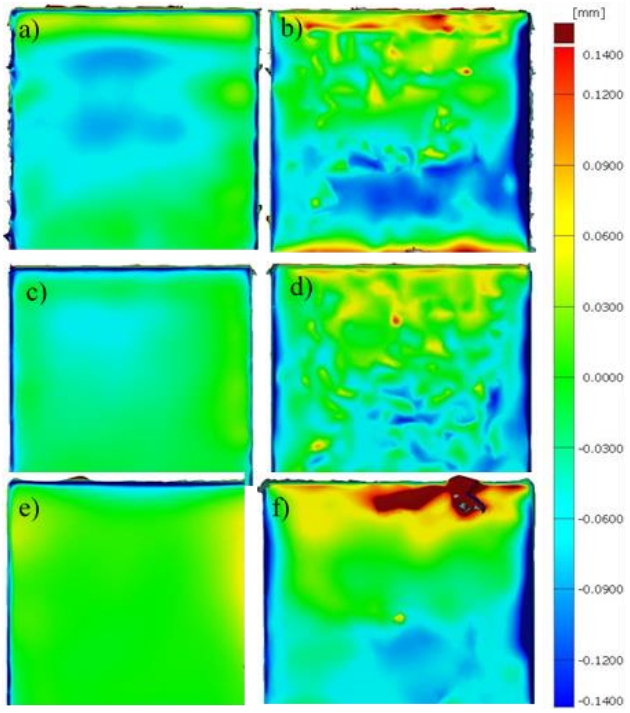

Fig 8. Bluelight measurements of specimens: a) upfacing surface of specimen 1, b) downfacing surface of specimen 1, c) upfacing surface of specimen 2, d) downfacing surface of specimen 2, e) upfacing surface of specimen 3, f) downfacing surface of specimen 3.

4. Conclusions

In the present study, the effect of contact-free support gap on dimensional deviation of LPBF produced overhang specimens were experimentally investigated. The main findings can be summarized as follows:

- ✓ There is a direct correlation between contact-free support gap and the dimensional variation. When contact-free support gap increases, average thickness deviation increases.
- ✓ The tip of all specimens showed higher distortions than the root of the specimens due to free edge effect.
- ✓ Downfacing surfaces of specimens showed higher and non-homogenous distortion than the upfacing surfaces due to the non-homogeneous behavior of the powders between contact-free support and the specimens.
- ✓ Some irregularities were observed on downfacing surfaces of the specimens. Fused particles are attached to the surface during melt pool penetration towards the powder bed and this is one of the main causes of thickness deviation.

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Author's statement

Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent has been obtained from all individuals included in this study. Ethical approval: The research related to human use complies with all the relevant national regulations, institutional policies and was performed in accordance with the tenets of the Helsinki Declaration, and has been approved by the authors' institutional review board or equivalent committee.

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