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Verification of 3D printers in X-, Y- and Z-directions

Hans N. Hansen[1], Jakob S. Nielsen[1], Jakob Rasmussen[1], David B. Pedersen[1]

[1]*Technical University of Denmark*

hnha@mek.dtu.dk

Abstract
Various approaches have been proposed to verify the performance of 3D printers including the so-called hole plate. However, there is an obvious drawback in printing a 2D artefact on a machine that is being used to print 3D parts. Conclusions regarding the performance in the third axis are not available. This paper sets the foundation for understanding the thermal behavior of the fused deposition modelling process so that in the future, an approach for 3D verification based on printing towers on a base plate can be developed. This foundation is set by means of an analysis of possible errors introduced by thermally induced residual stresses from material shrinkage during deposition.

3D printing, Verification, Tolerances, Fused deposition modelling

1. Introduction

Recently 3D printing has turned from a means of prototyping into a true viable manufacturing method. Therefore demands are set to the manufactured parts that are comparable to those known from conventional manufacturing. This paper expands the previous work on 2D verification of Additive Manufacturing processes by the authors [1,2], by investigating deformations from thermal stresses from lateral superstructures induced to substructures in the horizontal plane, in order to prepare to expand the methods towards 3D verification. This will allow comparison of 3D printers following the approach know from Coordinate Measurement Machines (CMM's) [3,4].

2. Method

In reference to Hansen et al. [1,2], a hole-plate was used to verify the horizontal performance of Fused Deposition Modelling (FDM). It was proposed that this verification method will be expanded to three dimensions by means of adding series of vertical superstructures to the artifact. These can then be measured to identify vertical dimensional accuracy. In order to safely do so, deformations in the horizontal sub-structural plane due to thermal effects from superstructural lateral calibration-features must be understood. This because the substructure forms the base for horizontal verification. A method to investigate these deformations in the vertical plane of the artifacts has been proposed, and can be used to quantify thermal residual stresses, the effect of horizontal dimensional accuracy from lateral superstructures and as such, this paper is presenting the above as a first step in order to quantify the FDM platforms spatial performance.

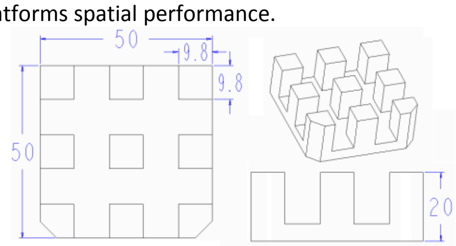

Figure 1. Layout of the calibration artefact. Tower layout is varied.

In the investigation, artefacts were produced in *Stratasys P430 ABS* on a *Stratasys Dimension 1200sst*, at full density. 3D digitization of the printed calibration artefacts was carried out using a *GOM ATOS Triple scan* 3D scanner with *SO170* optics. This scanner has been calibrated using a reference artefact provided by GOM, as well as an independent calibration of the scanner by means of calibrated and certified gauge blocks. The scanner was calibrated to an uncertainty of U=4,9 µm (95% confidence level). With respect to the dimensional accuracy of the FDM platform of +-0.1mm (example [1]), it renders the scanners uncertainty negligible. All inter-comparisons of 3D scans and CAD bodies were carried out by means of *ATOS Inspect Version 8*. Unless stated otherwise, a minimum of 8 3D scans forms the base for the analysis.

3. Results

In order to investigate how residual thermal stresses from superstructures affect the underlying structure, the following procedure has been used: A base has been 3D printed, and the geometrical deformation from thermal residual stresses has been quantified in terms of flatness deviations. Geometries containing a variety of super-structures shaped as pillars on the same base were 3D printed, and the geometrical deformation from thermal residual stresses has been quantified by relating the deformations to the artefact initially printed.

3.1. Base analysis and reference baseline stress contribution

In order to investigate the effect of the thermal residual stresses in the base of the artefacts; a base without pillars scanned prior to and after removal from the build plate. The scans were compared to quantify the deformation from the stress release. The deformation was within ±10µm and thus considered negligible. Nominal, global dimensions (fig. 1) were found to be generally smaller than specified, from 67 to 79µm in X and 60 to 62µm in Y. This is in accordance with the discoveries from previous studies, and appears unaffected by the number of pillars added to the base [3]. Subtracting the contribution from the residual stress deformation of the base plate from the plates with superstructures, will quantify the contribution from the superstructures alone. Throughout this paper the stress-contribution from the base plate will be referred to as the baseline stress-contribution and can be seen in fig. 2.

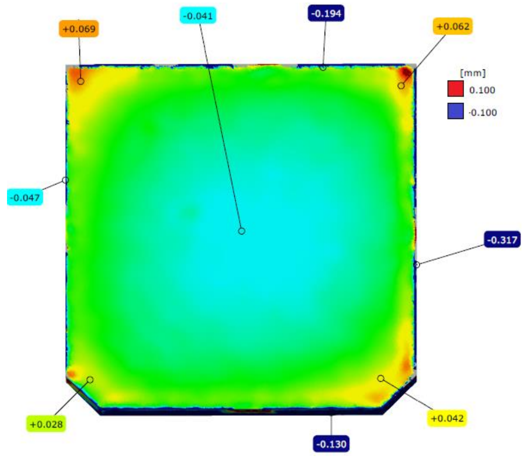

Figure 2. Baseline, deformations from thermal stresses measured using optical scanner. Numbers indicate deviations from ideal flat plane.

3.1. Analysis of thermally induced deformations a pillar

Comparing the baseline deformations with a similar plate with one pillar gives the contribution from a single superstructure.

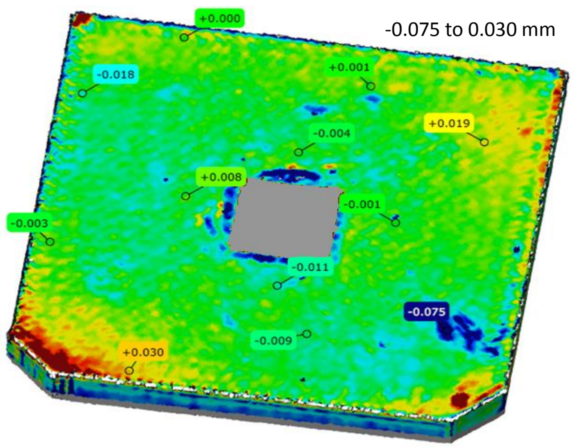

Figure 3. Baseline plate compared to one-pillar artefact. measured using optical scanner. Numbers indicate deviations in [mm] from reference plate as shown in fig. 2.

Seen in fig. 3, is a defect around the base of the one-pillar artefact shaped as a groove. This is believed to be a result of thermal contraction of cooling material further away from the ridge, and possibly from below the pillar itself, as indicated from fig. 4. It is believed that, as the build-chamber of the 3D printer is heated to near the glass-transition temperature (Tg) of the process-material, thermal shrinkage of the first layers of the pillar only affect a zone just adjacent to the pillar itself. This is where heat from the first layer of the pillar has propagated out into the base structure and momentarily elevated the temperature above Tg.

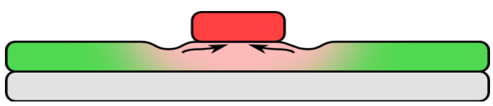

Figure 4. Groove effect surrounding pillars.

3.2. Analysis deformation interaction from several pillars

As the deformation mechanism from one pillar appear local, and only affects the global dimensions of the base to a negligible degree, a comparison was made of the base vs. a 5-pillar artefact. This is an attempt to investigate if pillars affect their neighbours. As multiple pillars are introduced (fig. 5), a slight trace of accumulated residual stress interaction between pillars is evident. This is seen as yellow-to-red zones when comparing the geometry to the baseline. The conformance is within -0.075 to +0.030mm. The local tendencies around pillars follow those seen in fig. 3, of the one-pillar artefact. It is noticed that the groove is still present in the upper right and lower left corner. The groove is present as green areas in otherwise red zones. The complexity of the stress-interaction is only slightly increased, and seen as upwards warping of the corners of the plate. Irrespective of this, the tendencies close to the pillars are the same, and predictable. An artefact with a total of 9 pillars was finally printed, and the trend followed that of the initial two. The conformance was comparable to the latter.

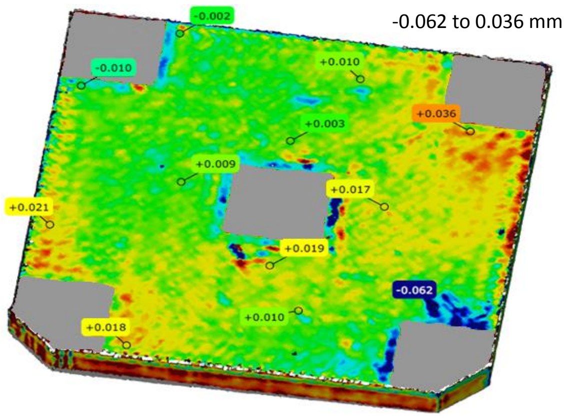

Figure 5. Baseline plate compared to nine-pillar artefact measured using optical scanner. Numbers indicate deviations in [mm] from reference plate as shown in fig. 2.

4. Discussion & Conclusions

A series of artefacts containing a number superstructural pillars has been compared in order to understand and quantify the effects of thermal stresses in parts manufactured by the FDM process. It was found that these structures mainly affect substructure locally, though a slight general warp of the substructure was detected. This knowledge is sought to be of high relevance when a three-dimensional calibration object is to be designed for true geometrical XYZ verification of the process. The discoveries show that a flat base can be printed and used for subsequent verification of the horizontal plane, and at the same time supporting pillars can be included that will mainly affect this plane locally. Hereby a superstructure for verification of the process in the vertical direction can be included in the geometry without much concern as to how this affect the base used for horizontal verification.

References:

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