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Reproducibility of 3D printed structures

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Abstract

Additive manufacturing – 3D printing is increasingly applied in the development project from idea to the finished product. With additive manufacturing it is possible to create products with complex geometry from 3D CAD model in very short time, which is very difficult or even impossible to do with other manufacturing technologies.

With all the advantages, from the very beginning of additive manufacturing, major drawback is the reproducibility of printed structures. Uniqueness of process results in a whole range of adverse effects on the printed product such as deviations from the expected length measures, deviations of form (roundness, cylindricity, straightness, etc.), deviations from the position (location, concentricity, symmetry, etc.), deviations from the orientation (parallel alignment, verticality, inclination angle) and the inability to achieve a uniform surface texture.

Test plate processed with PolyJet Matrix, with various typical geometries for this process will be printed and dimensional measuring, deviations of shape, position and orientation of the printed structures on test plate will be conducted using conventional measurement methods and X-ray Computed Tomography.

Keywords: Additive manufacturing, reproducibility, testing plate

1. Introduction

Every AM process has a limit on the smallest feature that it can create. PolyJet process has a resolution of 42 micron in the x- and y- directions with a layer thickness between 16 and 32 microns. While there has been some preliminary investigation with simple single material rib shapes, it is important to understand whether the minimum manufacturable feature size differs between materials, surface finish types (denoted in the printer as "matte" vs. "glossy"), part orientation, feature direction (embossed or debossed), and feature shape. [1]

A standardized test plate has been proposed by many authors for use in characterizing the products of AM processes. A test plate must include both rectangular and circular features to quantify the minimum feature size of the AM machine. As the high resolution of the PolyJet process is one of its primary advantages, authors in literature [1] suggested circular features with diameters from 1 mm to 0.1 mm, and rectangular features with widths from 1 mm to 0.1 mm and lengths from 3 mm to 0.3 mm. [1, 2]

In literature [3, 4] some rules are suggested for test artefacts for additive manufacturing standard accuracy test. Many authors tested dimensional accuracy of the same part, but for different process or for the same process but with different machines [5]. On the other hand, we investigated repeatability of the same machine.

2. Modeling of test plate

First experiment shows that PolyJet machine could not print circular feature with diameter less than 0.5 mm, and rectangular features with width less than 0.2 mm (Figure 1). As such, a new test plate was designed which maintains the same minimum feature test geometry, but with some modification. All test plates were produced in the same orientation to avoid influence of the machine and specification of process. Figure 1 shows final 3D CAD model of test plate. The smallest diameter is 0.5 mm, smallest rectangle width is 0.2 mm, with minimum spacing between features equal to 0.2 mm (Figure 2).

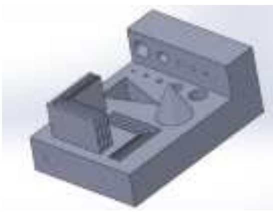

Figure 1. Final 3D CAD model of test plate

In study [6] authors find out that build style – surface finish types (matte and glossy) and layer thickness influence on dimensional accuracy. But for proposed small features in test plate in this work, matte finish type was not possible, because removal of support structure would destroy features in the test plate. Several procedures were performed for adjustment of the 3D printer: UV calibration, load cell calibration, head alignment, head optimization, vacuum calibration and calibration of the table.

Test plates were printed at one day intervals, with the same orientation and parameters.

3. Dimensional measurements

For the purpose of this research, two test plates processed with same production parameters were selected. Using 2D optical microscope with telecentric objective specific measurands on different geometrical features were measured. Results are given in table 1. Average values were calculated as arithmetical mean from three repeated measurement, and range is given as the difference between maximum and minimum value of the result. Images from microscope show significant deviations from ideal shape on different features (Figure 2).

Table 1. Measurement results

Measurand	Test plate No.1		Test plate No.2		*Δ**
	Average value	Range	Average value	Range	
Height of 1st raised L structure (mm)	5.9982	-	5.9964	-	-0.0018
Cone angle	52°43'48''	40'12''	52°45'12''	25'48''	1'24''
Angle between legs of isosceles triangle	33°9'12''	11'24''	33°25'48''	9''	16'36''
Width of 1st recessed L structure (mm)	0.5621	0.0099	0.5632	0.0016	0.0011
Width of 2nd recessed L structure (mm)	0.3652	0.0149	0.3567	0.0396	-0.0085

** Δ is calculated as difference between average values obtain on Test plates No.2 and Test plate No.1.*

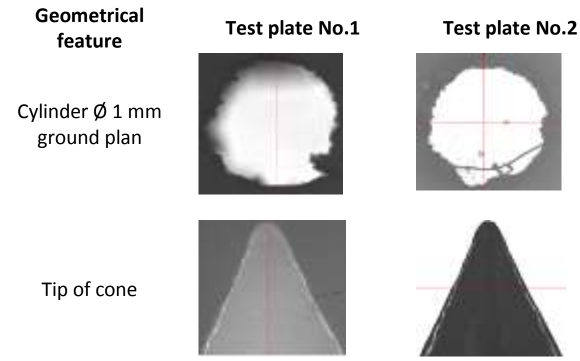

Figure 2. Deviations from designed shape

Additional dimensional measurements were made using a Nikon XT H 225 industrial computed tomography (XCT) machine. Radiography parameters were: X-ray energy 130 kV, X-ray tube current 160 µA, exposure time 500 ms. Imaging was performed using a 400 mm x 300 mm 14 bit flat panel detector with 127 µm pixel size. CT data was acquired with 1440 projections. Voxel size was calibrated by scanning a calibrated two sphere standard after scanning the sample (as a separate CT scan). Postprocessing was performed by beam hardening reduction using Hanning filter, noise reduction using a 3x3 median filter, and surface detection using an adaptive algorithm (Volume Graphics VGStudio Max 3).

Due to the fact that volumetric measurement data is obtained from XCT scanning, we were able to compare the entire volume of selected test plates to the ideal CAD volume. First the XCT scan was aligned to the CAD model using a least squares best-fit alignment, after which deviations from CAD model were calculated. A Histogram of these deviations is shown in Figures 3 and 4. These figures indicate that deviations from nominal values (errors in manufacturing of test plates) are contained within the range of ± 140 µm; additionally, it was calculated that 95% of deviations are smaller than ± 90 µm.

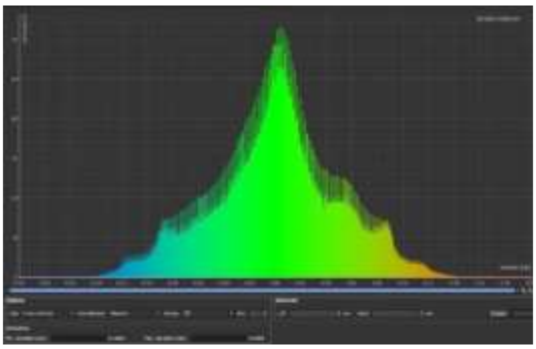

Figure 3. Deviations on Test plate No.1

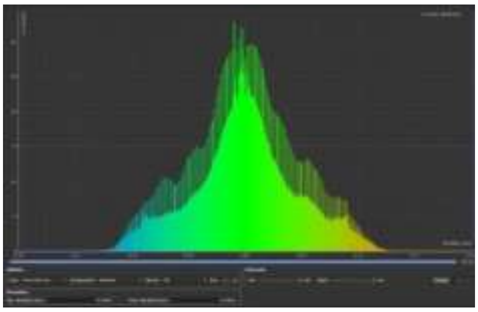

Figure 4. Deviations on Test plate No.2

4. Conclusion

A test plate is an important tool for evaluating the performance characteristics of various AM processes. Unlike previously published designs, a new test plate was designed specifically to evaluate which features are possible to be printed and which are not. Because PolyJet technology has some specific properties (e.g. layer thickness of just 0.016 mm, no shrinkage of the materials), the test plate was redesigned and adjusted for the PolyJet process.

It can be concluded that, using PolyJet, it is not possible to print holes with diameter smaller than 0.5 mm.

Furthermore, with these features in the test plate we wanted to find out accuracy/repeatability of same test plate built with same parameters, over period of a few days. Preliminary analysis shows that all deviations from nominal (ideal) geometry for the entire volume lie within ± 140 µm, and 95% of them are within ± 90 µm. Further research will focus on identification of geometrical features with largest deviations, characterization of those features, and determination of root causes for their occurrence. This method could be applied to other AM processes, with slight modifications to account for specific properties of selected AM process.

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