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BENCHMARKING OF MATERIAL JETTING PROCESS: PROCESS CAPABILITY STUDY

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ABSTRACT: The material jetting process is one of the most established additive manufacturing techniques to create three-dimensional (3D) components with high resolution. Nevertheless, there are limited literature on the manufacturing process constraints and capabilities. This paper aims to correlate building orientation to dimensional accuracy and surface quality in order to investigate the material jetting process capabilities and limitations. A benchmark test part was proposed to include the intended feature geometry for characterization. This analysis is important to provide the manufacturing constraints using this printing technique, while also serves as design guidelines for 3D functional part design.

KEYWORDS: 3D printing, Additive manufacturing, benchmarking, characterization, 3D material jetting

INTRODUCTION

Material jetting is an established additive manufacturing (AM) process to create components with high resolution and potential for multiple materials parts. The material jetting 3D printing technology is also capable of fabricating functional polymer components such as lightweight honeycombs (Yap, Lai, Zhou, & Yeong, 2014; Yap & Yeong, 2015), lifestyle wearable products (Yap & Yeong, 2014) as well as scaffolds for tissue engineering (Chua, Yeong, & Leong, 2005; Yeong, Chua, Leong, Chandrasekaran, & Lee, 2005). It is a liquid-based AM system that uses liquid photo-curable resin to build the objects. The material used ranges from clear, rubber-like and biocompatible photopolymers, to tough high performance thermoplastics (Chua & Leong, 2014). The advantages of material jetting process, such as 3D Systems ProJet and Stratasys PolyJet, include high quality, high accuracy, fast building speed, smooth surface finish, wide range of materials, and potential for multi-material printing.

In AM industry, benchmarks are used to indirectly evaluate the performance of an AM machine or a process. Many researchers have designed different benchmarks to evaluate the capabilities of AM systems. Castillo (2005) has designed an “open book” shape to test the capability of building various angles, overhangs, thin walls, and other fine features. Mahesh, Wong, Fuh, and Loh (2004) designed a benchmark to test the dimensional and form accuracy of different AM systems. Kumar and Kumar (2015) also designed a “twisted pillar” model to investigate the influence of different local surface angles and finish types on the surface roughness of Polyjet printed part. Moylan, Slotwinski, Cooke, Jurrens, and Donmez (2012) has proposed a standardized benchmark for AM. Their benchmark has incorporated many general features to test the capability of different machines or processes. However, this benchmark part is insensitive to the manufacturing process nor the application of the part.

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Fahad and Hopkinson (2012) have pointed out that the standardized benchmark proposed previously lacks the plane of symmetry to evaluate the repeatability of the features, so a new benchmark was proposed to solve this problem. Furthermore, benchmark parts should be designed specifically for the intention of use or the intended application. For example, Lee, Zhang, and Yeong (2016) have designed a benchmark specifically for microfluidic chip application to evaluate the printing resolution, accuracy, repeatability of PolyJet and FDM. In this work, the intention is to characterize the process capability of inkjet printing process, in term of dimensional accuracy and surface quality as a function of printing orientation. This information will be useful for designers and production engineers, to create first-time-right design and fabrication, while optimizing production yield. Printing orientation is a critical factor to determine the dimensional accuracy, surface quality, and strength property. However, this is often neglected and the orientation that minimizes materials and building time is more commonly used(Cazón, Morer, & Matey, 2014). Oh and Kim (2008) studied various parameters such as dimensional and geometric accuracy as well as surface roughness using material jetting process. However the effects of building orientation were not considered in this study. Kumar and Kumar (2015) also carried out the influence of local surface orientation influence on surface roughness using PolyJet printed twisted benchmark part but the effects on dimensional accuracy were not discussed.

This paper aims to propose a new benchmark part, specifically designed for investigating the process capabilities and limitations of the material jetting manufacturing process. This study characterizes the dimensional accuracy and the surface quality of the 3D built parts as a function of the building orientation.

EXPERIMENTAL METHODS

PolyJet material jetting process

Computer-aided design (CAD) model is uploaded to the Objet Studio Software, converted into STL file and then sliced into the required thickness (16μm or 32μm). During the building process, the jetting head moves along the x-y axis, jetting the required amount of photopolymer materials onto the build tray, according to the geometry of the horizontally sliced layer. The photopolymer is immediately fully cured by the two UV lamps on the jetting head (Meisel, 2015). The schematic is represented in Figure 1. Then the platform lowers correspondingly to the building layer thickness along the z-axis, and the next layer is built. The process is repeated until the whole model is completed (Chua & Leong, 2014).

Benchmark test design

In order to characterize the dimensional accuracy in terms of length, width and height, as well as the surface roughness of the PolyJet built parts in various X-Y orientations, a benchmark test part was designed and is shown in Figure 1. A total of 10 benchmark parts with different wall thickness, which varies from 0.2mm, 0.25mm, 0.3mm, 0.4mm, 0.6mm, 0.7mm, 0.8mm, 0.9mm and 1.0mm, were designed and printed. Each sample has 13 thin walls oriented at different angles ranging from 0 degree to 180 degree, with respect to y-axis of PolyJet building direction, with an increment of 15 degrees. The angle is increased in the clockwise direction, starting from positive y-axis, as shown in Figure 1.

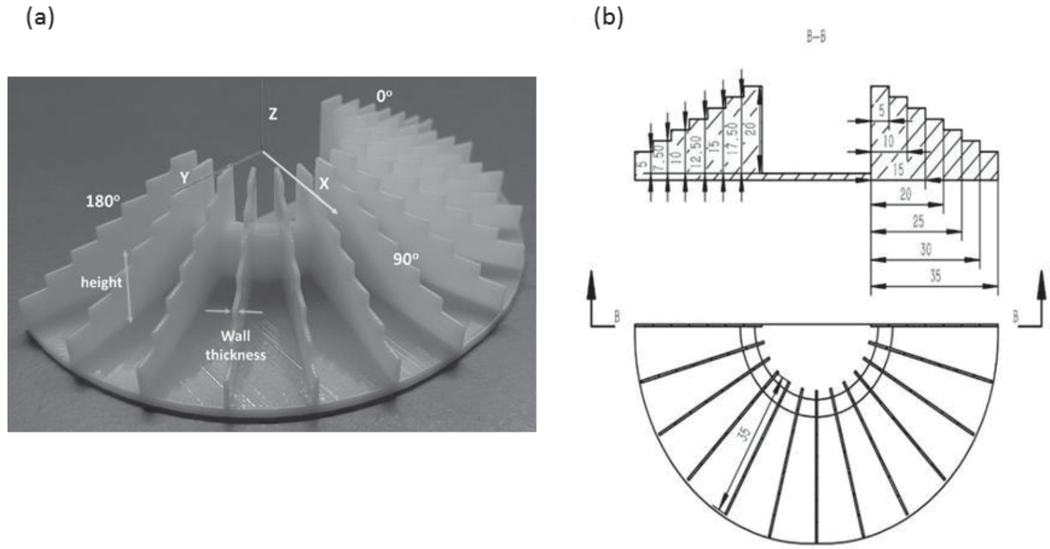

Figure 1. (a) PolyJet 3D printed benchmark part design for characterization of radial length, height and wall thickness; (b) dimensions of the features for characterization

Manufacturing

The benchmark test part was manufactured using PolyJet Objet500 Connex 3 with VeroWhitePlus RGD835 rigid opaque material. Glossy surface finish setting and digital material mode were selected for printing the parts.

RESULTS AND DISCUSSION

Surface quality

By using Plμ White Light Confocal Imaging Profiler, the 3-dimensional surface roughness of the benchmark part was measured on the benchmark with 1mm wall thickness, and the arithmetic mean (Ra) for various angles is recorded in Figure 2. The surface quality is relatively higher when the part is oriented at 0 deg, 45 deg, 90 deg, 120 deg, 135 deg and 180 deg. It is rougher at 30 deg, 75 deg, 105 deg and 150 deg. The graph is symmetric about the vertical line going through 90 degrees. When the part is fabricated using Polyjet, as the printing head is only travelling along x-axis when jetting materials, the surface texture varies at different angles. The difference in surface quality at different angles could be due to spreading of resin droplet and the alignment of nozzles in the printing head of PolyJet.

Dimensional accuracy

Height

The height of the thin walls was measured by Mitutoyo digital caliper with accuracy up to 0.01 mm. 10 samples were characterized, and 10 individual graphs for angle vs height are produced at different wall thickness. To simplify the presentation of the results, the 10 graphs were consolidated by only taking the deviation of the height from its corresponding nominal value as shown in Figure 3. The line charts represent the deviation for different height, ranging from 5 mm to 20 mm. It is observed from Figure 3(a) that the thin walls with wall thickness smaller than 0.3 mm have relatively larger deviation from its corresponding nominal value, implying that they cannot be built to the correct height regardless of the building orientation and built height. On the contrary, as illustrated in Figure 3(b), the deviation is not pronounced for wall thickness that is equal or larger than 0.3 mm. It can be concluded that in order to build the thin wall with high accuracy in height without defects, the wall thickness must be larger or equal to 0.3 mm.

Wall thickness

It is found out that when the wall thickness is greater than 0.5 mm, deviation of wall thickness tends to be consistent as shown in Figure 4. The only exception is at 0 degree, this could be because the direction of the thin wall built is perpendicular to the moving direction of the levelling roller, which is embedded and travels along with the printing head. The extra amount of material droplets were wiped off the wall, thus resulting in larger deviation on the wall thickness. The deviation from the corresponding nominal value and the percentage error for wall thickness is illustrated in Table 1.

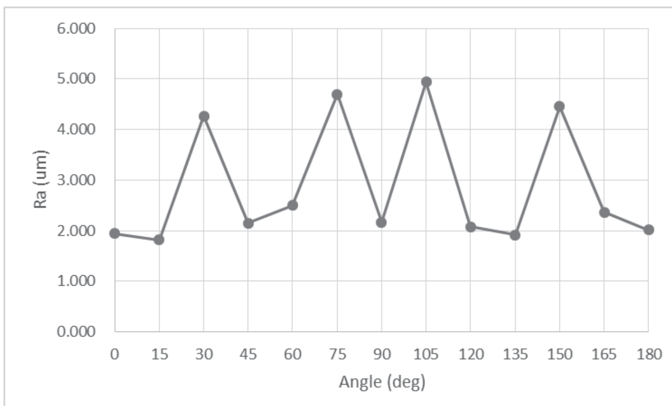

Figure 2. Effects of orientation on the surface roughness of the thin walls.

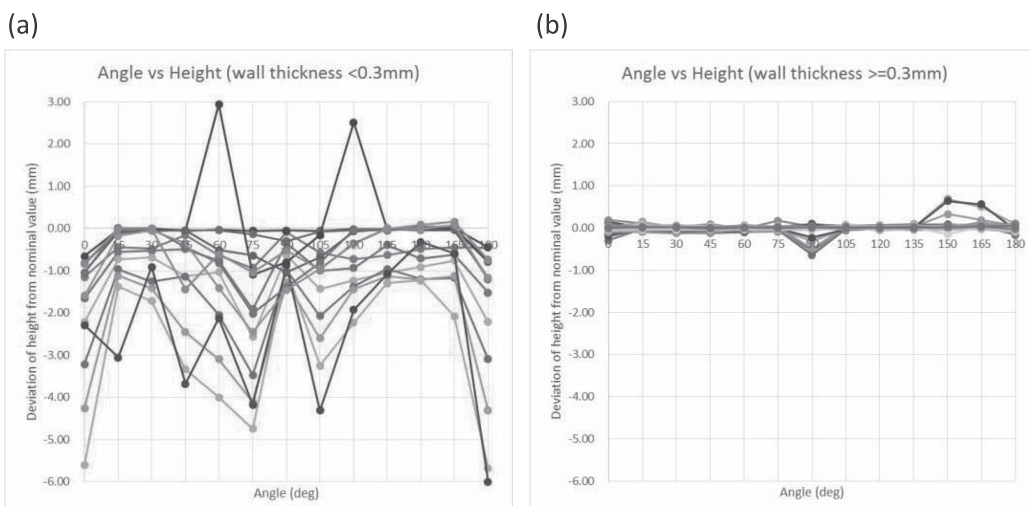

Figure 3. Deviation of height from nominal height against different angles for: (a) wall thickness < 0.3mm, (b) wall thickness ≥ 0.3mm

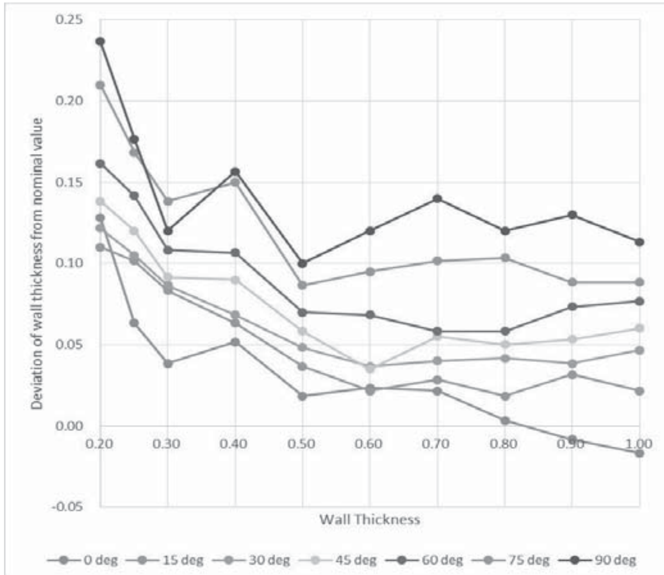

Figure 4. Deviation of wall thickness from nominal value

Table 1. Percentage deviation of wall thickness from nominal value

nominal wall thickness (mm)	Deviation percentage (%)						
	0°	15°	30°	45°	60°	75°	90°
0.5	3.67	7.33	9.67	11.67	14.00	17.33	20.00
0.6	3.89	3.61	6.11	5.83	11.39	15.83	20.00
0.7	3.10	4.05	5.71	7.86	8.33	14.52	20.00
0.8	0.42	2.29	5.21	6.25	7.29	12.92	15.00
0.9	-0.93	3.52	4.26	5.93	8.15	9.81	14.44
1.0	-1.67	2.17	4.67	6.00	7.67	8.83	11.33

CONCLUSION

In this paper, a PolyJet 3D printed benchmark part with the intention to correlate various X-Y printing orientation to the dimensional accuracy and surface quality has been characterized. The result shows the effects of printing orientation is significant on thin flat walls in terms of surface quality as well as dimensional accuracy. Thus this analysis is important to provide the PolyJet manufacturing constraints and guidelines to help designers to create 3D functional parts that conform to the design with less iteration. This work can be further extended to characterize other geometrical features and in the X-Z and Y-Z orientations.

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