

Effect of deposition speed on the flatness and cylindricity of parts produced by three dimensional printing process.

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Abstract. The idea of layer-by-layer deposition of materials to obtain three dimensional shapes, known as three dimensional printing, has gained much popularity during the last decade. Investigations related to understanding the effect of process parameters on the output of the accuracy of parts produced by three dimensional printing processes have been performed by various researchers. This study is also aimed at investigating the effect of deposition speed on the accuracy in terms of geometric dimensions and tolerancing such as flatness and cylindricity of the parts produced by open source three dimensional printers. The repeatability of the parts printed were also investigated.

1. Introduction

The concept of three dimensional printing (3DP) originated as rapid prototyping (RP) processes during mid-1980s. These processes were mainly aimed at producing a part in a tool-less manner by only using the computer-aided design (CAD) information of the part [1, 2]. The growth in technologies based on this concept of tool-less manufacture of products emerged to the level that the parts produced by these processes were successfully used in end-use applications and thus, were termed as additive manufacturing (AM) [3,4]. Society of Manufacturing Engineers (SME) and American Society for Testing and Materials (ASTM) define AM as “*A process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies*” [5]. A variety of techniques have been established to that fall under AM such as [3]:

Stereolithography (SL): based on curing a liquid photopolymer into solid shape by using ultraviolet light (laser) beam.

Selective Laser Sintering (SLS): based on sintering of powdered materials (polymers, ceramics and metals) using a high power laser beam.

Fused Deposition Modelling (FDM): based on extruding beads of semi-molten thermoplastics via small sized nozzle.

The cost of all these proprietary machines were very high and thus presented the major hurdle in wide-spread use of these technologies. However, after the expiration of major patents during 2008, the development of low cost, open source machines by a large number of manufacturers have enabled these AM processes to be operated by an increased number of users. The term 3DP, therefore, become popular among the users of AM techniques and is used synonymously in conjunction with the AM.



Due to its relatively simple and low cost technique of building parts, the technology utilized in FDM became the most popular open source 3DP technology and a large number of manufacturers of this technology are available resulting in a relatively large user-base of this technology.

Comparison among various 3DP processes [6-8], as well as assessment of the geometric accuracy of different 3DP processes [9-12] have been reported by many researchers over the last 15-20 years. Recently, many researchers have presented reports related to accuracy of parts produced by open source 3DP processes utilizing FDM technology [12-15]. Various parameters including layer thickness, deposition speed, materials flow rate and raster width etc. have been varied to evaluate their impact on the accuracy of parts produced in the previously mentioned reports. Although, the accuracy of part shape in terms of dimensions (i.e. length, height, diameter etc) have been evaluated, but, none of these studies reported the effect of process parameters on the form of the object in terms of geometric dimensioning and tolerancing (GD&T) such as flatness, straightness, and cylindricity etc. Also, very little attention have been paid to the repeatability of the parts produced by open source 3DP. Therefore, in this study, the effect of deposition speed is investigated on the accuracy in terms of the dimensional measurement as well as GD&T of shape of objects produced by open source 3DP processes. The repeatability was also investigated by building 3 parts at each different speed.

2. Experimental

The geometric benchmark part designed by Fahad et al [16] was used and only the one third section of the part was built as indicated in Figure 1. The parts were built using prusa mendel i3 printer using a poly-lactic acid (PLA) filament. Both the machine and material were purchased from a Chinese supplier. Three different deposition speeds were used including 35, 45 and 55 mm/sec. Three replicates at each speed were printed to evaluate repeatability. The layer thickness was held fixed at 0.15 mm and the extruder temperature was 200°C for all builds. An infill density of 30% was used for all the parts. The parts were measured using a Wenzel X Orbit 55 coordinate measurement machine (CMM) and a 2 mm diameter, ruby probe was used.

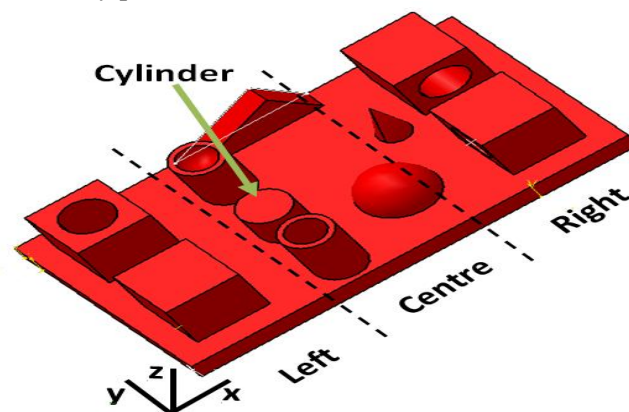


Figure 1. Benchmarking part used for measurements

3. Results and Discussion

3.1. Results

During the part build, slight curling of corners (i.e. left and right) was noticed therefore, it was decided to divide the base of part into three sections as left, centre and right (Figure 1) and five points within each section were measured to fit a plane and the flatness of each plane was recorded. The flatness values of each plane for all the parts are indicated in Figure 2. The solid cylinder (Figure 1) was also measured by taking a matrix of 4x4 points, that is, four points along the circumference of the circle at four different heights. The diameter and cylindricity of this solid cylinder for each part were recorded and the results obtained are indicated in Figures 3.

3.2. Discussion

As shown in Figure 2, it is very clear that the part base flatness deteriorates at higher speeds. Similar effect of speed on the accuracy of parts produced by open source 3DP process [14], however, for the purpose of comparison of flatness values, referenced can be made to a similar study conducted on sintering based 3DP processes [8]. This can be noted that the flatness values obtained are deteriorating with speed, however, the worst values obtained (i.e. near 0.4 for right section at 45 mm/sec, Figure 2.b) are better than those obtained for commercially established process (~ 0.7) [8].

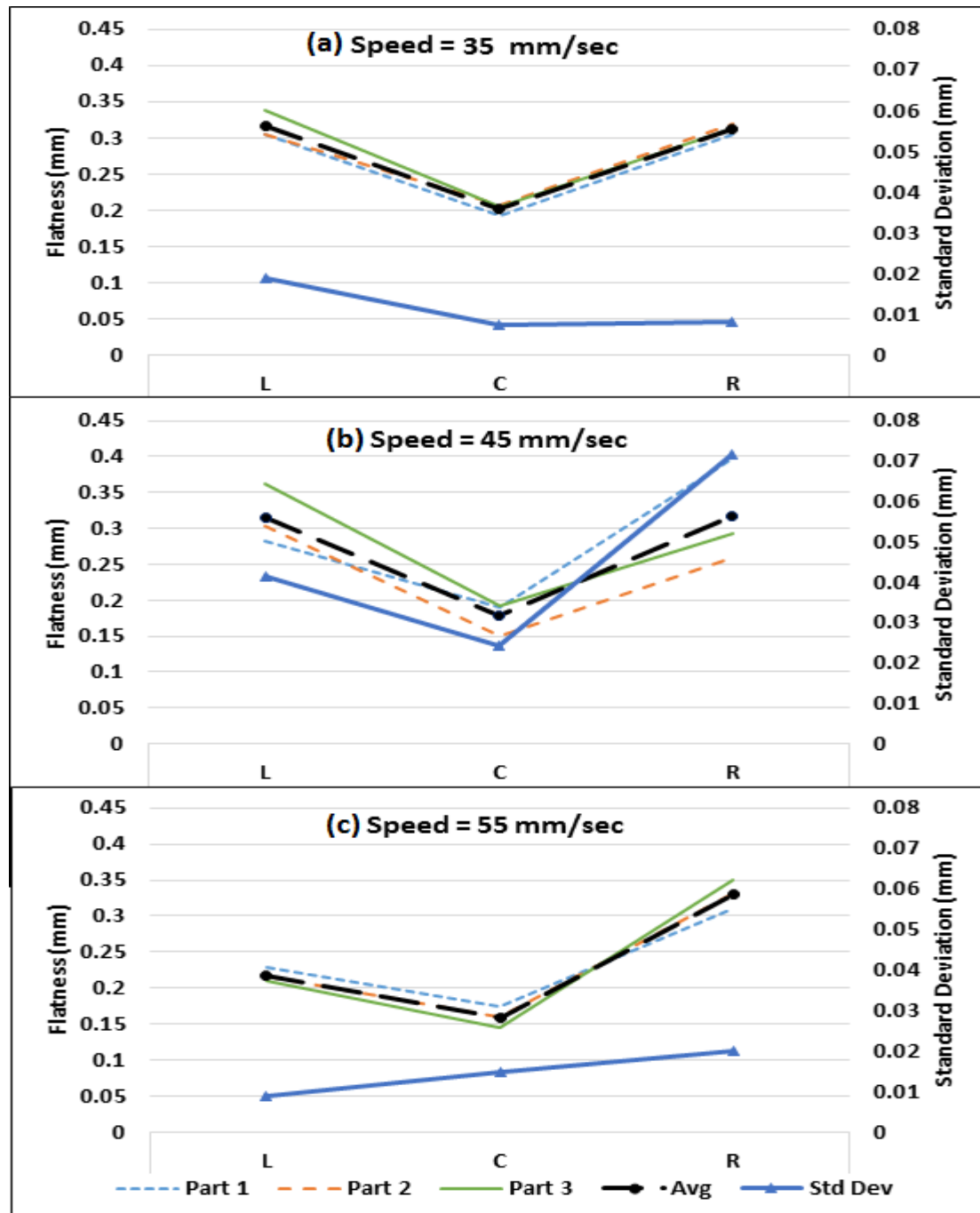


Figure 2. Flatness of left (L), centre (C) and right (R) sections of base at the three different speeds

It can also be noted for every speed, that the centre section has better flatness than the left and the right sections. This indicates the curling effect at the corner surfaces of the flat base for the part. The reason behind this flat base could be the same as reported by other researchers [8,17], that is, the thermal gradient. Due to the difference in temperature of the layer being deposited (hot) and the layer already deposited (cold), the hotter layer, during shrinking, pulls the previously deposited layer which had already shrink to attain its original dimension. This pulling effect causes the curling effect and thus the flatness at the centre is better than at the two corners. This can also be noted that not only the flatness values are better at lower speeds, but the repeatability is also better at slower speeds, this is indicated by a low standard deviation at 35 mm/sec (Figure 2.a) compared with those at 45 and 55 mm/sec. Similar trends were observed for the cylinder diameter and cylindricity value as indicated in Figure 3. The actual (designed) diameter of cylinder was 10 mm and it can be noted that at 35 mm/sec, the average value of cylinder dia was consistently near 9.8 mm (error of 0.2 mm) whereas at the highest speed, the average value of cylinder dia was near 9.85 m (error of 0.15 mm) but the variation among the three parts were high compared to those obtained for 35 mm/sec. Both the cylindricity values and the standard deviation in cylindricity values were better at 35 mm/sec compared with the two high speeds (i.e. 45 and 55 mm/sec). This, therefore, indicates that the slower speeds provide better accuracy in terms of geometric dimensioning and tolerancing and the repeatability of the parts is also better at slower speeds.

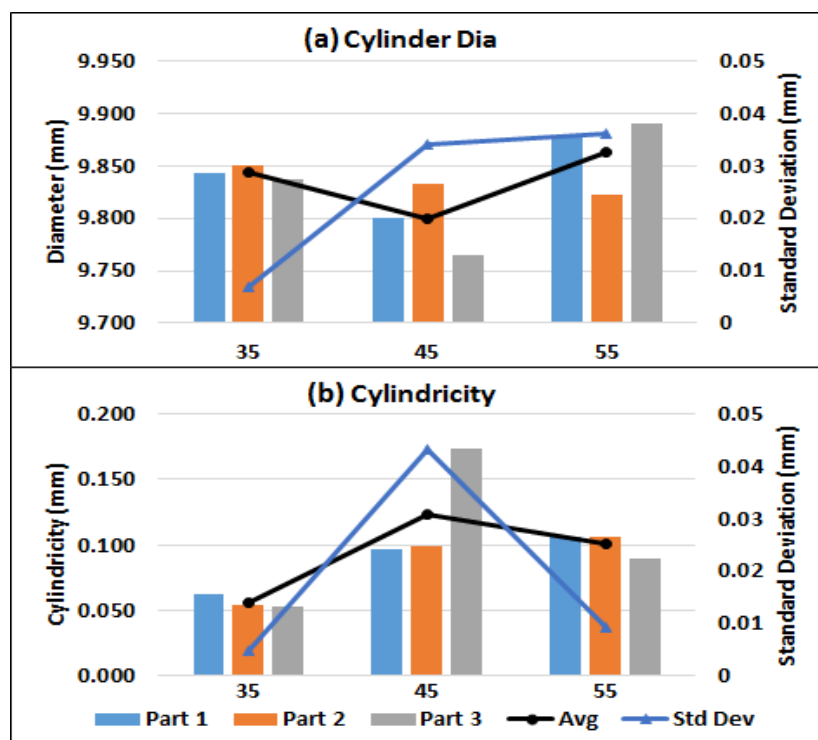


Figure 3. Values of (a) cylinder diameter and (b) cylindricity at different speeds

4. Conclusion

The accuracy and repeatability of parts produced by open source 3DP process was studied and the effect of variation in deposition speed was investigated. It was found that better geometric dimensions and tolerances were obtained at slower speeds. The obtained GD&Ts at slower speed also showed lower standard deviations compared with those at higher speeds indicating better repeatability at slower speeds.

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