IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

Error Analysis and Experimental Research on 3D Printing

IOP Conf. Series: Materials Science and Engineering **592** (2019) 012150 doi:10.1088/1757-899X/592/1/012150

Error Analysis and Experimental Research on 3D Printing

Zeng Lianghua[1] Zou Xinfeng[1]

[1]Beijing Institute of Technology, Zhuhai Campus, Jinfeng Road 6, Xiangzhou District, Zhuhai City, Guangdong Province

zhuhai09@sina.com xfzou_mo@outlook.com

Abstract. Precision is one of the important factors that restrict the application of 3D printing technology on industry. On the basis of Fused Deposition Modeling (FDM) of 3D printing experiments, this paper summarized the problems occurred during experiments, discussed the types of errors of 3D printing, and analyzed the errors by combing theoretical calculation and experiment.

1. Introduction

3D printing technology is based on the principle of slicing and stacking layer by layer. The printer slices the 3D model into a series of two-dimensional section outlines according to set layer thickness before printing, then it scans, prints and stacks layer by layer based on scanned data of these two-dimensional section outlines to create a three-dimensional object. The entire printing process includes the model format conversion, the layer parameter setting, the support parameter setting, the tool path setting and the solid-molten-solid state transition of the printing material, etc. The printing quality is affected by the software parameter setting, the outline recognition precision, the movement accuracy and stationarity of the printer structure, and postprocessing quality, etc. Based on the above information and combing 3D printing experiments, the author discussed and analyzed the errors in 3D printing, aimed at improving the precision of the printed object.

2. 3D Printing Error Types

In the entire printing process, the error types include slicing errors (related to model precision, data conversion and slice thickness), supporting errors (related to the placement, support angle and support method, etc. of the workpiece), scanning errors (related to scanning path, scanning speed, vibrating and reversing of the extruder head and outline recognition) and errors caused by the printing material performance, etc.

2.1. Slicing error

The 3D models created with softwares such as UG and Solidworks, needs to be saved as model data with certain accuracy, then converted to STL file format for 3D printing. There is principle error with STL data since it is generated by triangular planes approximation. There are open-source slicer softwares in the market but their precision of data conversion is generally low.

2.2. Supporting error

The 3D printer generally has only one extruder head which has no supporting capacity, so it needs control on the incline angle of the design model outline. As for high precision workpiece, using only

IOP Conf. Series: Materials Science and Engineering **592** (2019) 012150 doi:10.1088/1757-899X/592/1/012150

one extruder head may cause formation failure, toppling deformation or even malfunction. Therefore, it is of great significance to reduce the support error and set reasonable support to ensure precision.

2.3. Contraction error
The printing temperature of plastic material (e.g. ABS) in FDM is generally around 270°C. The working temperature of the base plate and forming space is around 70°C. Therefore, there is a difference of 200°C. Due to the expansion and contraction of the printing material, the workpiece will certainly contract when it drops to normal temperature.

2.4. Outline Recognition error
The three-dimensional model is sliced into a series of two-dimensional section outlines, whose basic elements are point and line. The outline shape of each layer could be regular square (consisting of only straight lines), circular arc (consisting of only curves), or others (consisting of straight lines and curves).

As for section outlines made of only curves, infinite approximation by straight lines is usually adopted. Median and interpolation principle is used to subdivide triangular planes. The more times of subdivision is executed, the higher precision the approximation achieves, as shown in Figure 1.

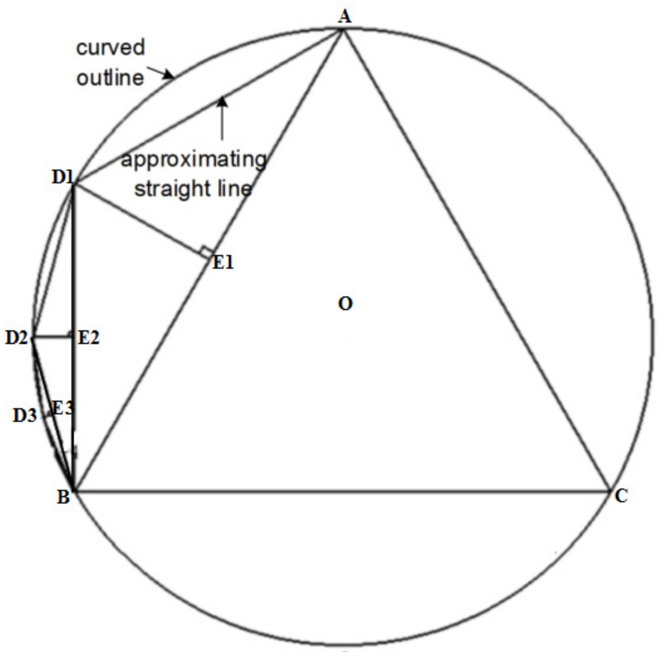
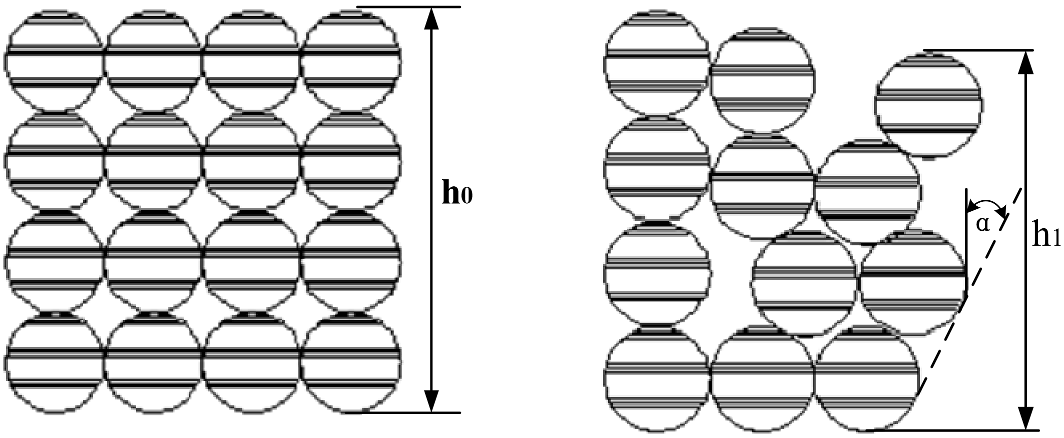


Figure 1. Curved section outline approximated by straight lines

The effective measures of reducing this kind of error is 1) to precisely recognize the two-dimensional section outlines of each layer by computer control, and 2) to optimize the printer structure to allow the extruder head's movement locus of the extruder head to infinitely approximate the outlines.

2.5. Height stacking error
The ideal stacking state of 3D printing is that all layers are stacked up well and in order, as shown in Figure 2 (a). However, in actual printing, the machine vibration, deformation caused by material phase transition, the support problem, and the blockage of the extruder head, always cause height error and perpendicularity error, as shown in Figure 2 (b). Comparing the practical and theoretical accumulating effect, practical height is obviously less than theoretical height (h1<h0), and the former has an angle error α in vertical direction.



(a) Ideal stacking effect (b) Actual stacking effect

Figure 2. Height error analysis

2.6. Extruder head vibration error

The 3D printer is usually structured to allow the baseplate to move in Z direction and the extruder head to move in X/Y direction. The computer controls the extruder head movement locus of the extruder head to realize recognition and scan of different section outlines. To fill curved outlines, the extruder head needs to reverse direction, stop and start for many times, which will cause vibration and affect accumulating effect, as shown in Figure 3.

Figure 3. Vibration causes misalignment & skrew

3. 3D Printing Error Analysis

There are many root causes of 3D printing errors. Among the above six types of errors, slicing error, outline recognition error, extruder head vibrating error and contraction error are related to machine software and hardware and printing material, such as software precision, control algorithm, machine structure and material performance. This paper only analyzed the height error and the support setting which are related to the printing process parameters.

3.1. Height Error Analysis

Stacking height reduction and perpendicularity error cause stacking inclination and then cause bending stress and bending deformation. With the increase of the printing layers, the stacking inclination forms a cantilever and extends out, as shown in Figure 4.

IOP Conf. Series: Materials Science and Engineering **592** (2019) 012150 doi:10.1088/1757-899X/592/1/012150

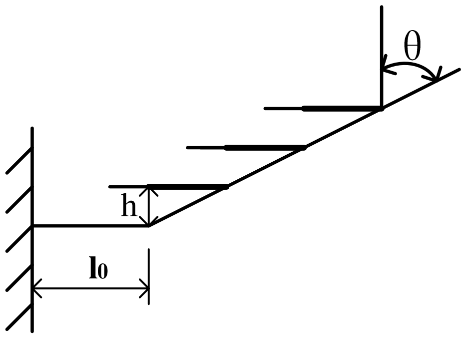


Figure 4. Height stacking error forms a cantilever

Let layer thickness is h, incline angle is θ, so the length increment of each layer is htanθ, and the 2nd layer bending moment M_2=htanθ · $(l_0 + \frac{1}{2}\text{htan}\theta)$, the 3rd layer bending moment M_3=htanθ · $(l_0 + \frac{1}{2}\text{htan}\theta + \text{htan}\theta) + M_2$, the 4th layer bending moment M_4=htanθ · $(l_0 + \frac{1}{2}\text{htan}\theta + 2\text{htan}\theta) + M_2 + M_3$, and son on. The bending moment increment of each layer $\Delta M = \text{htan}\theta[l_0+(x-2)\ \text{htan}\theta+\frac{1}{2}\text{htan}\theta]$. (Letting layer number is x).

The incline angle during printing is variable. Let it as θ_y, so the bending moment increment $\Delta M = \text{htan}\theta_y[l_0+(x-2)\ \text{htan}\theta_y+\frac{1}{2}\text{htan}\theta_y]$. The bending moment increment causes bending stress increase. When the bending stress increases to greater than the bond strength between layers, delamination and crack will occur, as shown in Figure 5. Based on the above analysis, the bending moment increment is closely and positive correlated with the layer number and the incline angle.

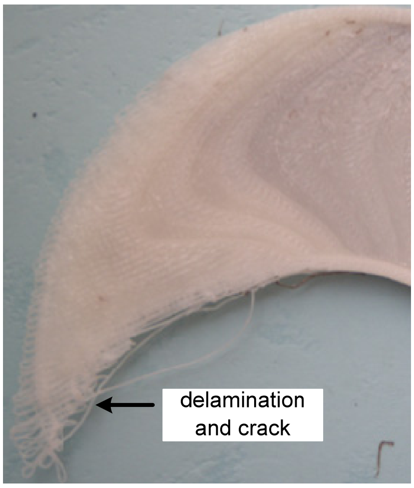


Figure 5. Delamination and crack

Besides, due to the extrusion of the extruder head and its own gravity, the extended part of each layer cause not only the bending moment but also the bending deformation (downward deflection and rotation angle), which will cause stacking error on height.

3.2. Supporting Setting Analysis

Appropriate support improves the forming precision. The support processing parameters include the support angle, the placement method and the support method. The support is divided into two types by function: one is support printed on the baseplate to prevent scratches on workpiece surface, and the another is additional support for non-vertical outlines to prevent deformation, delamination, crack and inclination, as shown in Figure 6.

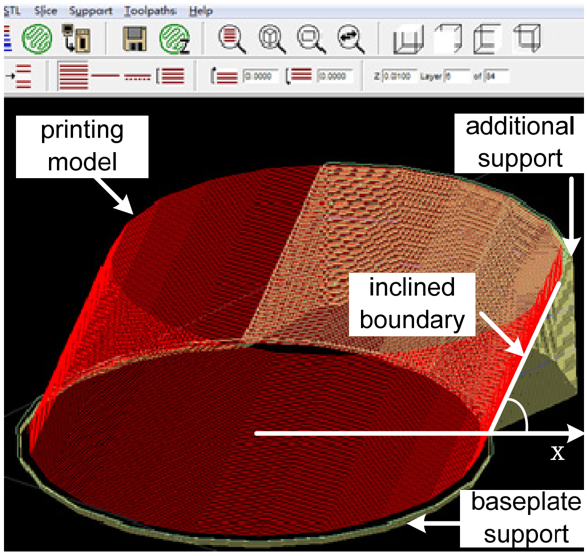


Figure 6. Support type

The authors simulated the support angle by insight software, changed the incline angle of the boundary on the model with the same dimensions (cylinder: diameter 60mm, height 20mm), set different support angles while keeping other parameters the same, and calculated the amount of material used on supporting by FDM Control Center software, which came to a comparison table as Table 1.

Table 1. Comparison of amount of material on supporting (Unit: in^3)

Boundary Incline Angle \ Support Angle	70°	60°	50°	45°	40°
40°	0.49	0.43	0.35	0.35	0.06
50°	0.35	0.28	0.06	0.06	0.06
60°	0.29	0.06	0.06	0.06	0.06
70°	0.06	0.06	0.06	0.06	0.06
80°	0.06	0.06	0.06	0.06	0.06

The above table shows, to ensure the printing precision of the same model, different support angles require different amount of materials on supporting, the larger the angle, the more materials are required. If with the same support angle, the smaller the boundary incline angle is, the less material on supporting are required.

4. Conclusion

This article summarized the 3D printing error types by combining theoretical analysis and experiments, analyzed the mechanics principle of the produce mechanism of height error, and illustrated the interrelation between the support angle setting and the model boundary incline angle by insight software.

Acknowledgment

Guangdong Ordinary Universities Youth Innovative Talents Project (3D Printing Quality Real-time Detection and Quality Prediction Key Technology Research：2018KQNCX343); Zhuhai Mechanical Engineering Dominant Discipline

References

[1] Kun He, Zhijun Yang 2018 Intelligent Fault Diagnosis of Delta 3D Printers Using Attitude Sensors Based on Support Vector Machines. *Senors* **18**:19-28

IOP Conf. Series: Materials Science and Engineering **592** (2019) 012150 doi:10.1088/1757-899X/592/1/012150

[2] Yedige Tlegenov, Geok Soon Hong, Wen Feng Lu 2018 Nozzle condition monitoring in 3D printing. *Robotics and Computer Integrated Manufacturing* **54**:45-55
[3] Barry Berman 2012 3-D printing: The new industrial revolution. *Business Horizons* **55**: 155-162
[4] Hongle Wang, Jiaxu Wang, Qinghua Zhou, Qingchun Xiong, Ziqi Wei 2017 Comprehensive Error Compensation Method of Numerical Control Machine Based on BP Neural Network. *Journal of Xi'an Jiaotong University* **6**:138~145
[5] Wenzhen Kuang, Feng Chang, Li Xu, Jiying Li. Rai 2017 Profile Recognition Based on Optimized Ant Colony Algorithm. *China Railway Science* **7**:8-13
[6] Yu Yao, Haiou Zhang, Gulan Zhang 2014 Counter Recognition and Defect Analysis on Metal Parts Direct Forming Deposition Layer. *Mechatronics* **3**:16~20
[7] Hanqing Zheng, An Gu, Mingyi Li, Xiangdong Cheng 2016 Applied Research on Object Contour Recognition Algorithm Instrumentation and testing technology. *Instrumentation and testing technology*,**35**:106~110
[8] Hongmei Shi, Hua Chai, Yao Wang 2015 Algorithm Research on Embedded Railway Identification Based on Target Recognition and Tracking. *Journal of Railway***7**:58-65