ATLANTIS PRESS
Advances in Social Science, Education and Humanities Research (ASSEHR), volume 300
2018 International Workshop on Education Reform and Social Sciences (ERSS 2018)

Analysis and Optimization of Warpage Deformation in 3D Printing Training Teaching -- Taking Jilin University Engineering Training Center as an Example

Dongni Geng [a], Jichang Zhao

Jilin University Engineering Training Center, Jilin University, Changchun 130022, China

[a] gengdongni2005@163.com

Abstract. Fused deposition (FDM) Is a typical rapid prototyping technology. In this paper, the 3D printer based on the principle of fused deposition molding produces warpage deformation during the printing model. By analyzing the root causes of warpage deformation during the 3D printing process of student engineering training, qualitative analysis of the effects of environmental temperature, print layer thickness, setting the bottom layer, standardizing student operations on the deformation of the model, and put forward corresponding measures to reduce the deformation of the model.

Keywords: 3D printing, warpage deformation, practical teaching, engineering training.

1. Introduction

Under the background of engineering education, colleges and universities are forming a teaching philosophy centered on cultivating students' comprehensive quality. The introduction of advanced 3D printing technology in the engineering training to cultivate students' practical ability and engineering innovation ability is conducive to broadening the knowledge of students, and it is a smooth transition for students to take up their posts in the future and adapt to work as soon as possible. The molding process of 3D printing technology belongs to “additive manufacturing”, which is a technology for manufacturing solid parts by means of material-by-layer accumulation of CAD design data, which is a manufacturing method of “bottom-up” material accumulation [1]. The technology can be widely used in the medical industry, cultural relics printing, industrial design, automotive parts manufacturing, aerospace and defense, geographic information systems and other fields. Therefore, the internship of 3D printing module in the course of engineering training is a great significance for promoting the innovation of new engineering construction and engineering education.

2. FDM Process

The basic principle of 3D printing technology is “layered printing, layer by layer”. Based on this principle, 3D printing technology is divided into five kinds of processes: fused deposition molding, photocuring stereo forming, selective laser sintering, and layer stacking manufacturing. Three-dimensional printing process, etc. The FDM process, also known as fused deposition, is a representative process for 3D printing. The instrumentation of the application is economical compared to other processes. The thermoplastic materials used in the equipment are ABS, PLA or nylon, and their melting points generally range from 100 to 300°C [2]. In the FDM process (fig. 1), the first step is to heat the nozzle to heat the filamentous hot-melt material (ABS, PLA) to a critical state. The maximum heating temperature is only about 2°C higher than the melting point of the material, and then the nozzle will be controlled by software. The two-dimensional geometric trajectory determined by the CAD of the lower layer model is squeezed, and the nozzle squeezes out the melted material, and the material instantly solidifies to form a contoured thin layer, and finally the self-adhesive layer of the wire is stacked layer by layer [3]. In summary, 3D printing technology is to reduce the original complex model, the traditional method can’t be processed or difficult to process products through dimensionality reduction.

3. Status of 3D Printing Training Module of Jilin University Engineering Training Center

The center requires students who participate in the 3D printing module engineering training to understand the molding principles and characteristics of various processes of 3D printing and to operate the 'New ai er de' 3D printer(fig.2) based on the FDM process. The printing material used in 3D printers is PLA, the scientific name polylactic acid. In the course of engineering training, students use the 3D modeling software CATIA to design one or several models. After the model is created, the ''New ai er de' 3D printer is used to print the model under the guidance of the teacher. Through the engineering training of this module, some engineering students are better. The ideas can be realized from virtual to reality, and students have a strong interest. However, there are often many problems in the printing model process, which leads to the failure of the model printing. The most common problem is that the edge of the model is warped, which causes the model to be deformed, which seriously wastes the printing materials and time.

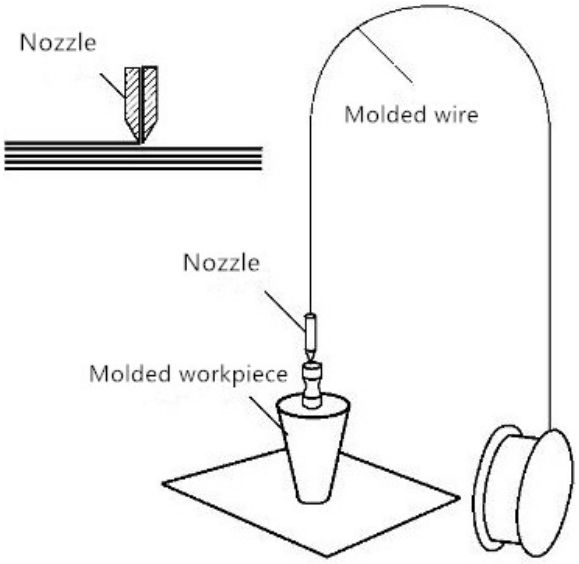


Figure 1. Process schematic

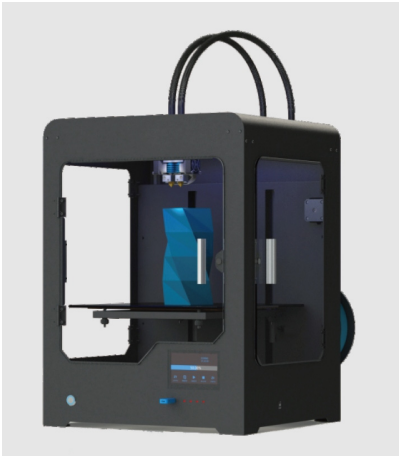


Figure 2. 'New ai er de' printer

4. Causes and Optimization of Warpage Deformation

In the FDM process, internal stress due to uneven shrinkage of the part of the part affects the dimensional accuracy of the prototype, causing the prototype to warp or causing delamination inside the prototype, and even damaging the support between the prototype and the table [4]. Students in the 3D printing module training, using the 3D printer to print the designed virtual model, in this process often appear printed edge warping (Figure 3). The wire undergoes a process of solidification to melting and then cooling and solidification during the molding process. Among them, in the process from melting to cooling, the internal stress of the printed material due to volume shrinkage causes the model to deform. Based on this theory, the author has carried out a large number of printing experiments and comparative analysis on the causes of warpage deformation of the model. The results show that the edge warping of the model is mainly caused by the uneven shrinkage of the material in the 3D printing model during cooling and solidification. So, to improve the edge warping of the 3D printing model, it mainly starts from the cause of uneven cooling and solidification shrinkage of the material.

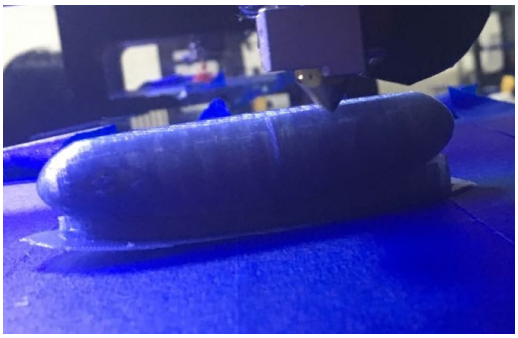


Figure 3. Model warping case

4.1 Ambient Temperature

The temperature of the 3D printing module operating room in the winter engineering training center is around 10°C. By comparison, under the same conditions, In the winter, students who participated in engineering training with the 3D printing module were more likely to have edge warpage in the printed model than when the summer temperature was high (Table 1), This situation indicates that temperature is the main cause of edge warping of the 3D printed model. A large number of printing experiments under different temperatures of the students show that when the temperature is too low, the printed material melts and the hot bed cannot be bonded together or edge warping occurs [6]. If the model is printed at a lower temperature, there are two ways to reduce the occurrence of model warpage: one can take the form of preheating the printing platform in advance, and the other can maintain the room temperature at 20°C by heating. In fact, both of these methods improve the print quality by slowing the heat conduction and convection heat dissipation during the molding process, reducing the cooling rate, and thus slowing the solidification shrinkage stress at the edge of the model to reduce the warpage of the edge and to achieve the purpose of improving print quality.

Table 1. Comparison of warpage at different temperatures

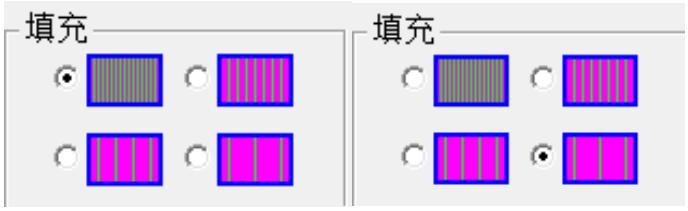
Temperature(ºC)	Warping rate(%)
10ºC	About 50%
15ºC	About 30%
20ºC	About 10%

4.2 Reduce the Print Layer Thickness of the Model

The geometric meaning of the layer height value refers to the spacing of adjacent layers when slicing the STL model file [7]. That is, the thickness of a layer printed on the FDM printer nozzle. This type of printing can cause significant discontinuities between layers, a phenomenon known as "stair phenomenon". The layer thickness of ‘New ai er de’ 3D printer is set from 0.15-0.4mm. Each layer is separated by 0.05mm. There are 6 parameters to choose from. The original print thickness of 0.25mm or larger is changed to 0.15mm or 0.20mm, through the setting of this parameter, the layer height value is reduced, and the step phenomenon is reduced, which can reduce the temperature difference of the newly added layer thickness and the top layer of the upper layer when cooling, and can also reduce the difference of different parts. The material shrinks unevenly, achieving the purpose of reducing the warpage of the edge of the model.

4.3 Reduce the Packing Density inside the Model

The ‘New ai er de’ 3D printer fills this item in the print settings. The set fill mode is changed from the original figure 4 .1 to figure 4 .2. The change of this setting can reduce the filling amount inside the model. As a result, the amount of force that the filler material causes to drive deformation upon cooling is reduced. This not only reduces the overall printing time of the model, reduces the use of printed materials, but also greatly reduces the force inside the plastic while reducing the possibility of warpage of the edges of the printed model.



4.1 4.2

Figure 4. fill mode

4.4 Standardize Student Operations

After the model is printed, some students do not take the plastic platform down but directly use the blade to shovel the model or excess material on the machine. Due to these improper operations, the height of the 3D printer printing platform relative to the print head has changed or the print platform has not been level. Students continue to use the 3D printers that have problems with the platform, and the model is prone to edge warping during the molding process. Therefore, it is necessary to standardize the preparation work before the students print, and the correct operation of the 3D printer by the students is also a prerequisite for avoiding model warpage and printing high quality models.

5. Summary

This article has in-depth exploration of the problem of printing failures in the process of using 3D printer printing model for students who participated in engineering training in the 3D printing module of Jilin University Engineering Training Center. When the students print the model, they can find the complicated factors that cause the warp deformation problem in the model by changing some conditions and combining a large number of engineering training practices. The results show that increasing the ambient temperature, reducing the print layer thickness, speeding up the printing speed, reducing the internal filling amount, standardizing the student operation can effectively reduce the occurrence of warpage and deformation, and improve the chances of students printing satisfactory products during the engineering training process. It is helpful for students who follow the follow-up engineering training to print high quality models.

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