Experimental Research on 3D Printing Process of Square Hole

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Abstract—The paper designs a square hole model and uses a delta3D printer to carry out printing experiments with different process parameters. It mainly conducts experimental research on four process parameters, including printing speed, layer thickness, filling density and platform temperature. The paper carries out the analysis of the influence of process parameters on the external dimensions of the hole, the inner depth of the hole, etc., and grasps the law of the influence of different process parameters on various sizes in order to provide a certain reference for the research of the 3D printing process of special parts.

1.INTRODUCTION

As a relatively common part, the square hole has the function that the round hole does not have. It can usually play the role of positioning and anti-rotation during the structural design and assembly. The traditional method of processing square holes has certain drawbacks, such as the need to individually design tools and fixtures, and the processing cost is relatively high. 3D printing can process parts of any shape without being affected by the complexity of the parts. 3D printing technology has obvious advantages for difficult-to-machine parts with complex structures. How to improve its forming geometric accuracy and how to demonstrate its cost-effective advantages and expand its application range for desktop-level 3D printers, is a problem that manufacturers and users are generally concerned about \cite{1}. Dimensional accuracy is one of the important indicators to measure the printing quality. In order to make the parts interchangeable, the consistency of the size must be ensured. The size is required to be within a reasonable range \cite{2}.

Wang Kai \cite{1} et al. carries out research on accuracy management and error compensation of FDM-3D printers, mainly conducting theoretical analysis and prediction of various errors, and proposes error compensation algorithms. Zhang \cite{2} et al. carries out the basic geometric error analysis of the fused deposition molding desktop 3D printer. Zhang mainly designs special-shaped models and carries out printing experiments under different process parameters to explore the influence of process parameters on printing errors and roughness. Qu \cite{3} et al. studies the influence of ambient temperature on the accuracy of 3D printing.

The paper carries out experimental research on square hole by 3D printing, and explores the influence of printing speed, layer thickness, filling density and platform temperature on the external dimension of the square hole and the inner depth of the hole.
2. PRINTING MODEL DESIGN
The designed square hole has a square shape with two square holes inside. The contour of the part consists entirely of linear contours. The length, width and height of the outer shape are 15 (C=15 mm); the length and width of first inner hole is 10 (A1=10 mm) and the depth is 5 (S1=5mm); the depth of second inner hole is 10 (S2=10mm), the length and width is 5mm. In the experiment the influence of process parameters on the four dimensions of shape length and width C, inner hole length and width A1, depth S1 and depth S2 are mainly studied. The design model is shown in Figure 1.

![Figure 1. Square hole](image1)

3. EXPERIMENTAL PROGRAM DESIGN
According to the adjustable process parameters in the slicing software, the experiment mainly studies the printing speed v, the layer thickness h, the printing platform temperature T and the filling density ρ. The paper divides the experiment into four groups and the printing temperature is fixed at 200℃. Each group is controlled to change only one printing parameter. The designed experimental program is shown in Table 1. In the experiment, a parallel-arm 3D printer is used and three parallel-arm linkage nozzles are used for printing. The printer uses the principle of fused deposition and the printing material is ABS. The experimental equipment is shown in Figure 2.

![Figure 2. Experimental equipment](image2)
### Table 1. Experimental Program

| Serial number | Printing speed $v$ | Layer thickness $h$ | Filling density $\rho$ | Platform temperature $T$ |
|---------------|-------------------|---------------------|------------------------|--------------------------|
| 1             | $v_1=30\text{mm/s}$, $v_2=40\text{mm/s}$, $v_3=50\text{mm/s}$, $v_4=60\text{mm/s}$ | $h=0.1\text{mm}$   | $\rho=20\%$           | $T=60\text{\degree C}$ |
| 2             | $v=50\text{mm/s}$ | $h_1=0.1\text{mm}$, $h_2=0.2\text{mm}$, $h_3=0.3\text{mm}$, $h_4=0.4\text{mm}$ | $\rho=20\%$           | $T=60\text{\degree C}$ |
| 3             | $v=50\text{mm/s}$ | $h=0.1\text{mm}$   | $\rho_1=10\%$, $\rho_2=20\%$, $\rho_3=30\%$, $\rho_4=40\%$ | $T=60\text{\degree C}$ |
| 4             | $v=50\text{mm/s}$ | $h=0.1\text{mm}$   | $\rho=20\%$           | $T_1=40\text{\degree C}$, $T_2=50\text{\degree C}$, $T_3=60\text{\degree C}$, $T_4=70\text{\degree C}$ |

### 4. Analysis of Results

1) Analysis of the influence of printing speed

According to the design program, 4 parts are printed at different printing speeds $v_1=30\text{mm/s}$, $v_2=40\text{mm/s}$, $v_3=50\text{mm/s}$ and $v_4=60\text{mm/s}$. The printed physical object is shown in Figure 3. The printed physical models under other parameters are omitted. The size is measured by using a caliper, and the average of each size is measured 3 times. The graph produced is shown in Figure 4.
It can be seen from Figure 4:
1) The printing speed has little effect on the length and width dimensions. With the increase of printing speed, the shape length and width C and the inner hole length and width A1 are basically unchanged.
2) The length and width of the shape show a negative deviation and the length and width of the inner hole show a positive deviation. Because there are square holes inside, the shrinkage stress and thermal stress of the material are relieved to a certain extent.
3) The printing speed has an obvious influence on the depth size. As the printing speed increases, the inner hole depth S1 shows an increasing trend and gradually stabilizes. The inner hole depth S2 basically showed a downward trend and gradually stabilized. The sample with a printing speed of 30mm/s is printed for the first time. There is agglomerate in the nozzle, which causes a large error.
4) From the perspective of the error value of all sizes, the accuracy is the highest when the printing speed v3=50mm/s.
2) Analysis of the influence of layer thickness
According to the design program, the measured results of printed objects with different layer thicknesses are made into a graph as shown in Figure 5.

![Figure 5. The effect of layer thickness](image)

It can be seen from Figure 5:
1) As the layer thickness increases, the shape length and width show an increasing trend, and gradually change from negative deviation to positive deviation. The length and width of the inner shape fluctuate slightly, all of which are positive deviations.
2) The inner hole depth S1 shows an increasing trend, all of which are positive deviations. The inner hole depth S2 fluctuates slightly, all of which are positive deviations.
   When the layered thickness is 0.3mm and 0.4mm, the size error of the inner hole depth (S1, S2) reaches 0.4mm. The greater the layer thickness, the greater the longitudinal spacing between layers, and the greater the impact on the depth dimension.
3) From the perspective of the error value of all dimensions, the accuracy is higher when the layer thickness is smaller. [5]
3) Analysis of the influence of filling density
According to the design program, the measured results of printed objects with different filling density are made into a graph as shown in Figure 6.
It can be seen from Figure 6:

1) The filling density has a great influence on the length and width dimensions. The influence degree of the inner shape and the outer shape is opposite. As the filling density increases, the length and width dimensions of the shape show an increasing trend, the error value gradually decreases and all errors are negative deviations. The length and width dimensions of the inner shape show a decreasing trend, and the error value gradually decreases and all are positive deviations. The higher the printing density, the smaller the layer spacing, and the higher the accuracy of the internal and external dimensions.

2) The depth of the inner hole basically increases, and the increase of S1 is not large. When S2 increases, there is an extreme point at $\rho_3=30\%$.

3) From the perspective of the error value of all dimensions, the accuracy is higher when the filling density is a larger value.

4) Analysis of the influence of platform temperature

According to the design program, the measured results of printed objects with different platform temperature are made into a graph as shown in Figure 7.
It can be seen from Figure 7:

1) The platform temperature has a slight fluctuation on the length and width of the shape, and the shape error is a negative deviation. As the platform temperature increases, the length and width of the inner shape gradually increase, and all are positive deviations.

2) The platform temperature has little effect on the depth of the inner hole. As the platform temperature increases, the depth of the inner hole basically tends to be stable.

3) From the perspective of the error of all dimensions, the accuracy is highest when the platform temperature $T_2$ equals 50°C.

5. CONCLUSION

From the experimental results, different process parameters have different influence degrees and trends on different types of sizes, which are mainly reflected in the error deviation direction and the change trend of the error value. Each error will affect the overall accuracy of the printed objects. From the perspective of the overall error, the accuracy is the highest when the printing speed $v_3$ equals 50mm/s. When the layer thickness is smaller ($h_1=0.1$mm), the accuracy is higher. The accuracy is higher when the filling density is larger ($\rho_4=40\%$). The accuracy is highest when the platform temperature $T_2$ equals 50°C. In order to ensure the printing accuracy, the printing model can be designed reasonably, and then the appropriate process parameters can be selected, taking into account factors such as printing time and required accuracy.

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