Fused Deposition 3D Printing of Bonsai Tree Guiding Mold Based on Acrylonitrile-Butadiene-Styrene Copolymer

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Bonsai is a kind of classical art in China and Japan. The traditional method of bonsai shaping of miniature trees is technical and usually requires experienced horticulturists to successfully carry out the process. In order to let ordinary people feel the fun of bonsai shaping, this paper proposes a fast bonsai shaping method, *i.e.*, by use of a plastic guiding mold with customized shape, which is processed by fused deposition 3D printing technology. The tree seedling is bundled onto the mold, and the shape of the mold guides the growth of the tree seedling, thus achieving the purpose of bonsai shaping. In order to further improve the bending properties of the bonsai guiding mold, this paper investigated the main 3D printing parameters of ABS filament. The results showed that with the decrease of printing speed, the increase of extrusion temperature, and the increase of hot bed temperature, the bending strength and elastic modulus of ABS specimens increased, and the bending properties was enhanced; the optimal printing speed was 50 mm/s, the extrusion temperature was 230 °C, and the hot bed temperature was 80 °C. The mechanical properties of the bonsai guiding mold manufactured based on the optimal process parameters were better, the print quality was higher, and it had high practical value.

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Keywords: Tree bonsai; Guiding mold; ABS; 3D printing

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INTRODUCTION

Bonsai is a kind of classical art in China and Japan, and "tree bonsai" is one of the main types of bonsai. This art form takes trees as the main body. The living tree becomes a participant, along with the creator's aesthetic interests. After pruning, shaping, coiling, and other creative techniques, the artisan arranges them in pots, reproducing the nature of the lone tree or jungle divine appearance of the artwork (Deng *et al*. 2023). The traditional method of tree bonsai shaping employs wire to wrap around the tree trunk. The wire is twisted to achieve the bending of the tree trunk (as shown in Fig. 1). As a result, the traditional method of shaping bonsai is somewhat technical and usually requires experienced horticulturists to achieve the desired result (Ding *et al*. 2022). In order to let ordinary people enjoy bonsai creation, this paper proposes a fast bonsai shaping method *via* usage of a plastic guiding mold with customized shape. Such a mold can be prepared by fused deposition 3D printing technology. Then the tree seedling is bundled onto the mold, and the shape of the mold guides the growth of the tree seedling, thus achieving the desired shaping effect.

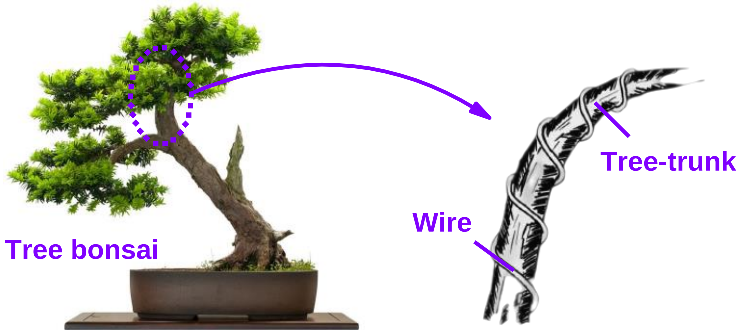

Fig. 1. Traditional method of tree bonsai shaping

Compared with traditional plastic processing methods such as injection molding and hot pressing, the application of 3D printing technology to process tree bonsai guiding mold has unique advantages (Han *et al*. 2022). First of all, 3D printing can achieve personalised customisation, combining computer-aided design and 3D printing to quickly design and manufacture unique shaped bonsai guiding mold, so that ordinary people can also enjoy the fun of bonsai creation (Huang *et al*. 2022). Secondly, 3D printing has the characteristics of rapid response, from the design model to print the finished product, 3D printing can be completed in a short period of time, high efficiency, greatly reducing the production cycle (Xia and Yan 2024).

Usually, when a bonsai tree is processed for shaping, the tree trunk is forced to undergo multiple bending in response to the guiding mold (Zhang *et al*. 2023). The tree trunk will give a reaction force to the guiding mold to resist the bending deformation, which puts high requirements on the bending properties of 3D-printed bonsai guiding mold (Feng *et al*. 2022). Therefore, in the present work, acrylonitrile-styrene-butadiene copolymer (ABS) filament, which has excellent mechanical properties among the commonly used consumables for 3D printing, was selected (Yang *et al*. 2022). ABS is a common 3D printing consumable with a wide range of uses, and it is a polymer material with high strength, good rigidity, easy to be processed and modeled, and it can be recycled (Yu *et al*. 2023). In this work, the main 3D printing parameters (printing speed, extrusion temperature, hot bed temperature) of ABS filament were investigated, the optimal process parameters to improve its bending properties were summarized, and the 3D printing practice was carried out on a customized bonsai guiding mold.

EXPERIMENTAL

Materials

The ABS filament (1.75 mm diameter, White, Anycubic, Shenzhen, China) was used for additive manufacturing by fused deposition method.

Specimen Preparation

In order to investigate the effects of the main 3D printing parameters (printing speed, extrusion temperature, hot bed temperature) on the bending properties of ABS filament, three-point bending tests were conducted on fused deposition 3D-printed ABS specimens. A rectangular model (160 mm in length, 15 mm in width, and 8 mm in height, as shown in Fig. 2a) was designed using Solidworks software (Dassault Systemes, Education Version 2016, Paris, France) as the specimen for this experiment, followed by the export of an STL file, which was imported into Cura software (Ultimaker, Version 4.5, Gelderland, Netherlands) to be sliced, and a G-code file was exported for 3D printing (Li *et al*. 2020). A Kobra-2 3D printer (XYZ printing, 0.4-mm nozzle diameter, Anycubic, Shenzhen, China) was used for additive manufacturing by fused deposition method. The main printing parameters for rectangular specimens were set as follows: the filling rate was set to 50%, the extrusion flow rate was set to 100%, and the fill pattern was set to grid type (Zhou *et al*. 2023).

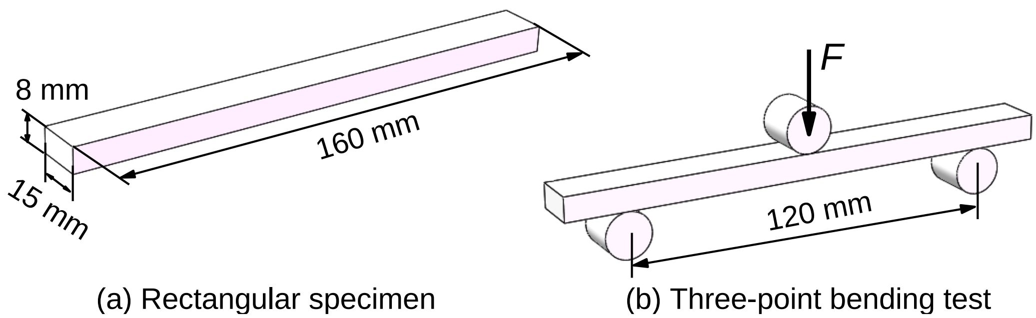

Fig. 2. Rectangular specimen and three-point bending test

Three-point Bending Test

The bending properties of plastics are commonly tested by the three-point bending test, which is performed as follows: a rectangular specimen is placed across two supports (with a spacing of 120 mm between the supports, as shown in Fig. 2b), and the load (*F*) is applied to the top centre of the specimen *via* a loading indenter (Li *et al*. 2022). Under the bending load, the specimen will be deformed in bending until it breaks. The load applied to the specimen by the loading indenter during this process is measured and the properties, such as bending strength and elastic modulus, are calculated (Liu *et al*. 2021).

RESULTS AND DISCUSSION

Effect of Printing Speed on the Bending Properties of ABS Specimens

Printing speed refers to the moving speed of the extrusion head (Yu and Wu 2024). Three-point bending tests were conducted on four groups of ABS specimens (three samples in each group) with printing speeds of 20, 30, 40, and 50 mm/s, and the test results are shown in Fig. 3. As is apparent from the figure, the bending strength and elastic modulus of the ABS specimens increased as the printing speed decreased. This is because in the actual printing process, as the printing speed decreases, the flow time of the fused ABS on the surface of the solidified filament increases, and it spreads more fully under the action of surface tension (Liu *et al*. 2020). In addition, as the printing speed decreases, the contact time between the fused ABS and the neighbouring ABS filament becomes longer, the ABS molecules spread more fully, more molecular chain segments are entangled, and the interlayer adhesion properties of the ABS specimens are enhanced (Zou *et al*. 2023). As a result, the bending strength and elastic modulus of the ABS specimens increase, and the bending properties are improved.

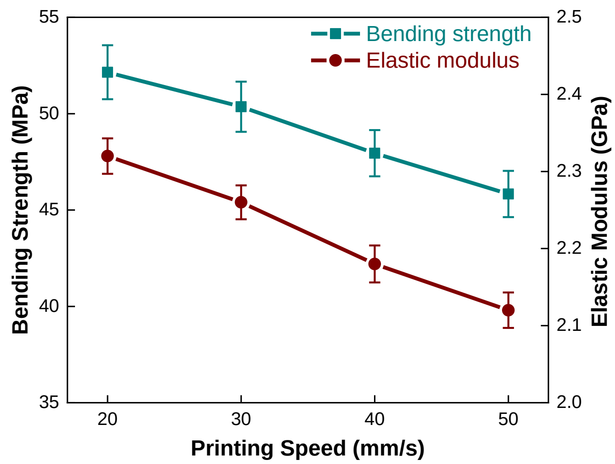

Fig. 3. Effect of printing speed on the bending properties of ABS specimens

Effect of Extrusion Temperature on Bending Properties of ABS Specimens

Extrusion temperature refers to the temperature when the extrusion head heats the filament to the molten state. Three-point bending tests were conducted on four groups of ABS specimens (three samples in each group) with printing temperatures of 200, 210, 220, and 230 °C, and the test results are shown in Fig. 4. It is apparent that the bending strength and elastic modulus of the ABS specimens increased as the extrusion temperature increased. This can be attributed to the fact that as the extrusion temperature increases, the cooling time of the fused ABS from the viscous flow temperature (210 °C) to the glass transition temperature (100 °C) becomes longer, and the spreading area of the fused ABS on the surface of the solidified filament becomes larger (Mo *et al*. 2022). In addition, with the increase of extrusion temperature, the diffusion of the molecular chain segments of the ABS filament at the adhesive interface is accelerated, more molecular chain segments produce entanglements, more intermolecular forces such as van der Waals forces are formed, and the interfacial adhesive properties of the ABS specimens are enhanced (Qi *et al*. 2023). As a result, the bending strength and elastic modulus of the ABS specimens increase, and the bending properties are enhanced.

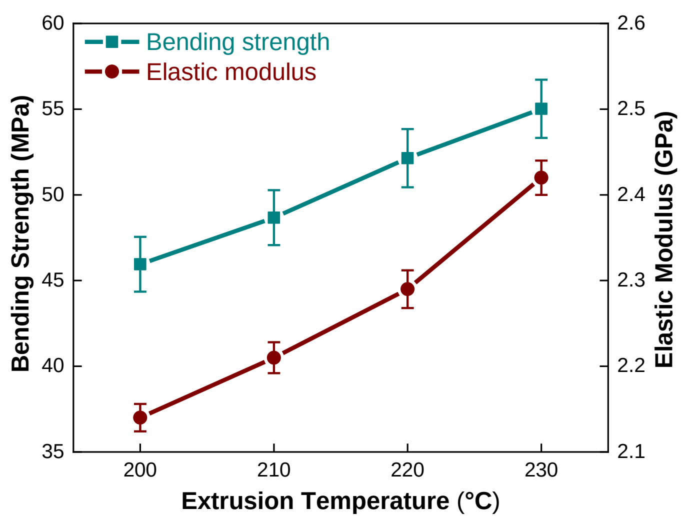

Fig. 4. Effect of extrusion temperature on the bending properties of ABS specimens

Effect of Hot Bed Temperature on the Bending Properties of ABS Specimens

The hot bed is the platform for bonding the bottom surface of the 3D-printed model. Three-point bending tests were conducted on four groups of ABS specimens (three samples in each group) with hot bed temperatures of 50, 60, 70, and 80 °C, and the test results are shown in Fig. 5. The bending strength and elastic modulus of the ABS specimens were found to increase as the hot bed temperature increased. This is because the heat from the hot bed is transferred on the one hand by means of heat conduction to the bottom shells of the ABS specimens in contact with the hot bed. On the other hand, the heat is transferred to the side walls of the ABS specimens *via* air heat convection (Wang *et al*. 2023). The heat conduction induces more adequate diffusion and entanglement between adjacent filaments of the bottom shells of the ABS specimens, and similarly, the heat convection induces more adequate diffusion and entanglement between adjacent filaments of the side walls of the ABS specimens (Zhou *et al*. 2022). As a result, the bending strength and elastic modulus of the ABS specimens increase, and the bending properties are enhanced.

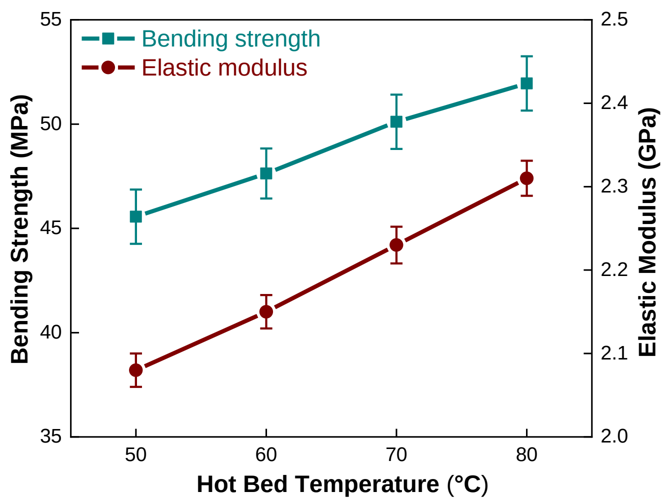

Fig. 5. Effect of hot bed temperature on the bending properties of ABS specimens

STYLING DESIGN AND 3D PRINTING

Solidworks software was applied to design the 3D model of the bonsai guiding mold. The 3D model took the heart motif as the basic element, and the styling scheme was designed through the sketching module (as shown in Fig. 6), and the solid features were created using the stretch bump command. Subsequently, the created 3D model was exported to an STL file and imported to Cura software for slicing. The warping problem of the bottom layer of the model needs to be controlled during the slicing process. Due to the large thermal shrinkage of ABS, it is easy to deform when it is cooled and solidified, which leads to the separation of the bottom layer of the model from the hot bed. To solve this problem, it is necessary to set up a skirt for the bottom layer of the model when slicing. The role of the skirt is to increase the contact area between the bottom layer of the model and the hot bed, to effectively increase the adhesion between the bottom layer of the model and the hot bed, and to avoid warping problems.

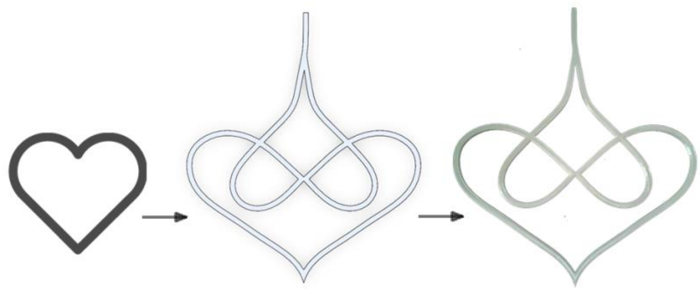

Fig. 6. Styling design and 3D printing

To effectively improve the bending properties of the bonsai guiding mold, the process parameters were set with reference to the results of the three-point bending test, in which the printing speed was 50 mm/s, the extrusion temperature was 230 °C, and the hot bed temperature was 80 °C. Because the bonsai guiding mold was long and thin component, to improve its structural strength and stiffness, the internal filling rate was set to 100%, and the extrusion flow rate was set to 100%. The rest of the process parameters adopted conventional settings, such as cooling fan speed of 6000 rpm, printing acceleration of 1000 mm/s^2, *etc.* The final printed model is shown in Fig. 6. The bonsai guiding mold manufactured based on the optimal process parameters was found to have suitable mechanical properties and high print quality.

PRACTICE OF BONSAI SHAPING

3D-printed guiding mold was applied to tree bonsai shaping. *Diospyros cathayensis* was chosen as the tree seedling. *D. cathayensis* is a small tree in the persimmon family with small glossy leaves, rounded fruits, and orange-red colour when ripe, and is one of the most popular species for bonsai. *D. cathayensis* is easy to bud, has a long flexible trunk, and has many branches, which makes its overall shape conducive to shaping.

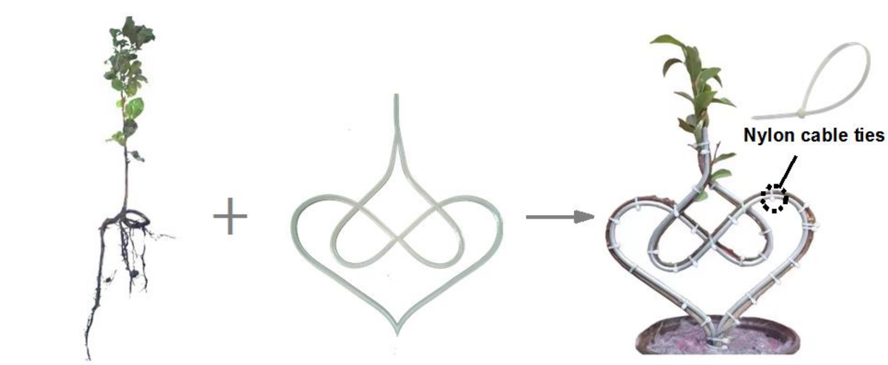

Fig. 7. Bonsai shaping effect

In the bonsai shaping process, the roots of *D. cathayensis* are first buried in a pot filled with nutritious soil. Self-locking nylon cable ties are then used to secure the trunk of *D. cathayensis* to the guiding mold, causing the slender trunk to bend along the shape of the guiding mold, that is to say, guiding the growth of the tree seedling through the shape of the mold (shown in Fig. 5), and finally, when *D. cathayensis* grows to a certain shape and the guiding mold is removed, *D. cathayensis* will keep the shape of the guiding mold, thus achieving the purpose of bonsai shaping. The completed bonsai shaping effect is shown in Fig. 7.

CONCLUSIONS

1. "Tree bonsai" is a kind of classical art in China and Japan. In order to let ordinary people also feel the fun of bonsai shaping, this paper proposes a fast bonsai shaping method, based on using a plastic guiding mold with custom shape. The mold is prepared by fused deposition 3D printing technology. Then the tree seedling is bundled onto the mold, and the shape of the mold guides the growth of the tree seedling, thus achieving the purpose of bonsai shaping.
2. In order to further improve the bending properties of the bonsai guiding mold, this paper investigated the main 3D printing parameters of ABS filament. The results showed that with the decreasing of printing speed, the increasing of extrusion temperature, and the increasing of hot bed temperature, the bending strength and elastic modulus of ABS specimens increased, and the bending properties was enhanced; the optimal printing speed was 50 mm/s, the extrusion temperature was 230 °C, and the hot bed temperature was 80 °C. The mechanical properties of the bonsai guiding mold manufactured based on the optimal process parameters were better, the print quality was higher, and it had high practical value.

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