Design and Fused Deposition Modeling of Furniture Risers Using Polyamide Filament

Chen Wang,[a,b,]* Hanyi Huang,[a] Shanxiang Xu,[a] and Jiahao Yu [b]

Fused deposition modeling (FDM) 3D printing technology was used to customize furniture risers to match furniture dimensions and children's body sizes. The goal was to achieve a rapid, safe, and sustainable height adjustment solution for children's furniture. Polyamide (PA) filament was chosen as the printing material. Compression tests were performed to investigate the properties of the 3D-printed PA models under varying process parameters, including layer thickness, infill density, and heated bed temperature. Experiments showed that as the layer thickness decreased, the infill density and the heated bed temperature increased. The compressive strength and compressive modulus of the PA model gradually increased, and the compressive properties improved. The optimized process parameters for compressive properties were: layer thickness (0.1 mm), infill density (90%), and heated bed temperature (90 °C). Using these parameters, this study completed the fabrication of furniture risers *via* FDM 3D printing. The 3D-printed furniture risers exhibited excellent compressive strength and surface finish, and they allowed for quick height adjustment to accommodate children's varying body sizes. Moreover, the 3D printing approach itself was cost-effective and highly efficient. These benefits collectively highlight the application value of 3D printing for customized furniture components in promoting children's healthy growth and saving resources.

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Keywords: Furniture risers; Fused deposition modeling; 3D printing; PA filament

*Contact information: a: College of Furnishings and Industrial Design, Nanjing Forestry University, Nanjing 210037, China; b: Jiangsu Co-Innovation Center of Efficient Processing and Utilization of Forest Resources, Jiangsu, China; *Corresponding author: 996869559@qq.com*

INTRODUCTION

Furniture directly impacts users' practical experience through its functionality and comfort (Chen *et al.* 2022). In daily life, the need for reasonable elevation of furniture has become commonplace, driven by considerations such as functional optimization or ergonomics (Li *et al.* 2023). This requirement is particularly pronounced in the realm of children's furniture. As children undergo rapid growth and development, their height, sitting height, and behavioral patterns can change greatly within short periods. However, conventional mass-produced children's furniture predominantly employ fixed structures, making it difficult to dynamically adapt to a child's changing dimensions. This imposes an economic burden through frequent furniture replacements and potential health risks to spinal development from prolonged use of ill-fitting furniture (Hu *et al.* 2024).

Against this backdrop, exploring a rapid, safe, and sustainable solution for adjusting the height of children's furniture has become paramount. The 3D printing technology, with its high degree of design freedom and rapid customization capabilities, offers an innovative pathway towards achieving this objective (Feng *et al.* 2022). This study employed 3D printing to customize furniture risers, matching specific furniture dimensions and children's body sizes and enabling accurate height adjustment of children's furniture. This approach extends the lifespan of such furniture, optimizes the user experience for children, and promotes their healthy development.

Fused Deposition Modelling (FDM) technology has become one of the most widely applied 3D printing techniques due to its advantages of low equipment costs, straightforward operation, and diverse material compatibility (Wang *et al.* 2019). The principle of FDM technology involves heating thermoplastic filament within the printer nozzle to achieve a molten state. Computer-controlled nozzle movement then deposits this melt layer by layer onto a heated bed, producing the product prototype (Zhang *et al.* 2023). This layer-by-layer additive manufacturing approach demonstrates exceptional rapid prototyping capabilities, offering a short manufacturing cycle from digital model to physical prototype. It is particularly well-suited for small-batch, customized production requirements. Among numerous FDM 3D printing materials, polyamide (PA) filament stands out as a high-performance option. Its high tensile strength, excellent toughness, and superior chemical resistance makes it particularly suitable for manufacturing products subjected to load-bearing, impact forces, or requiring functional mobility. Consequently, this study applies FDM 3D printing technology with PA filament to the design and fabrication of customized risers for children's furniture.

EXPERIMENTAL

Materials

The filament used for FDM 3D printing was a commercial blue Polyamide 6 (PA6, Miracle 3D, Suzhou, China) with a diameter of 1.75 mm, a density of 1.14 g/cm^3, and a melting point of approximately 230 °C (Hang *et al.* 2025).

Specimen Preparation

The compressive properties of furniture risers are crucial for their service life, as they are the primary load-bearing components. Therefore, this study aims to enhance the compressive properties of 3D-printed risers by evaluating the influence of layer thickness, infill density, and heated bed temperature *via* compression testing.

Compression tests were conducted in accordance with the ASTM D695-15 standard. Cylindrical specimens with a diameter of 12.7 mm and a height of 25.4 mm were designed using SolidWorks software (Dassault Systèmes, Education Version 2016, Paris, France). These specimens were then fabricated using an FDM 3D printer (Anycubic, Shenzhen, China) equipped with a 0.4 mm nozzle. A total of 45 specimens were printed (15 specimens for each process parameter). The following parameters were held constant: extrusion temperature at 230 °C, extrusion flow rate at 15 mm^3/s, sidewall thickness at 0.8 mm, and infill pattern as grid (Huang *et al.* 2022).

Performance Test

In accordance with the ASTM D695-15 standard, compression tests were performed on the PA models using a universal mechanical testing machine (AG-X, 20 kN capacity, Shimadzu, Kyoto, Japan). Each model was axially aligned between the machine's upper and lower compression plates. A quasi-static loading condition was applied at a constant crosshead speed of 1 mm/min until failure (Li *et al.* 2022).

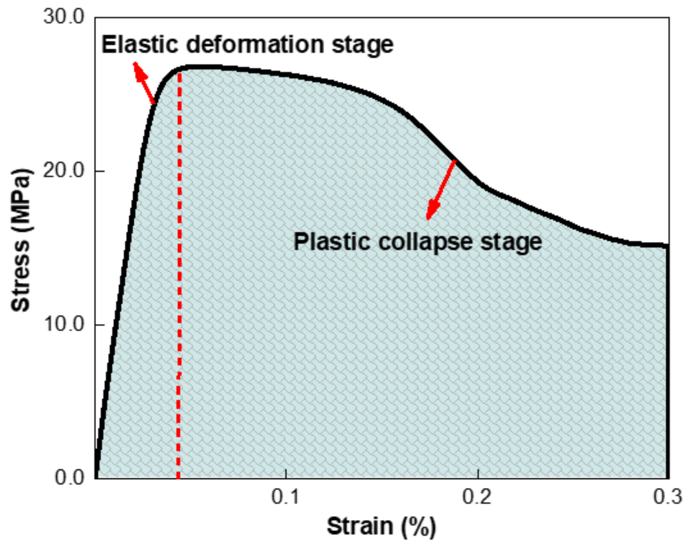

Fig. 1. Stress-strain curve of the PA model

According to the analysis of the stress-strain curve (Fig. 1) of the PA model used in the pre-experiment, the compression deformation process was mainly dividable into two stages: elastic deformation and plastic collapse. In the stage of elastic deformation, stress and strain exhibited a linear relationship, and the sidewalls and internal infill structures of the PA model underwent recoverable elastic deformation (Wang *et al.* 2023). When the stress reached its peak, the model entered the plastic collapse stage (Yang *et al.* 2022). At this point, the internal infill structure of the model underwent unstable buckling under continuous compressive loading, and interlayer cracking occurred on the sidewalls, leading to overall structural failure.

RESULTS AND DISCUSSION

Effect of Layer Thickness on the Compressive Properties of PA Models

The infill density was set to 90% and the heated bed temperature to 90 °C. Compressive properties of PA models were tested at different layer thicknesses (0.1, 0.2, and 0.3 mm). As evident from Fig. 2, both the compressive strength and compressive modulus of the PA models progressively increased as the layer thickness decreased. This occurred because, as layer thickness decreased, the distance between the 3D printer nozzle and the already-formed layer became shorter, enhancing thermal conduction. Consequently, the freshly extruded melt underwent more thorough molecular chain entanglement with the solidified melt, forming a stronger interlayer bonding interface. This robust interface effectively suppressed interlayer delamination failure under compressive loading, promoting a failure mode shift towards interlayer shear slippage. This enhanced the PA model's resistance to failure (Mo *et al.* 2022). Conversely, larger layer thicknesses weakened thermal conduction between adjacent layers, leading to poor interlayer fusion. This resulted in weak interfaces and porosity defects, making the PA model more susceptible to failure during compression. Therefore, reducing layer thickness was beneficial for enhancing the compressive properties of PA models.

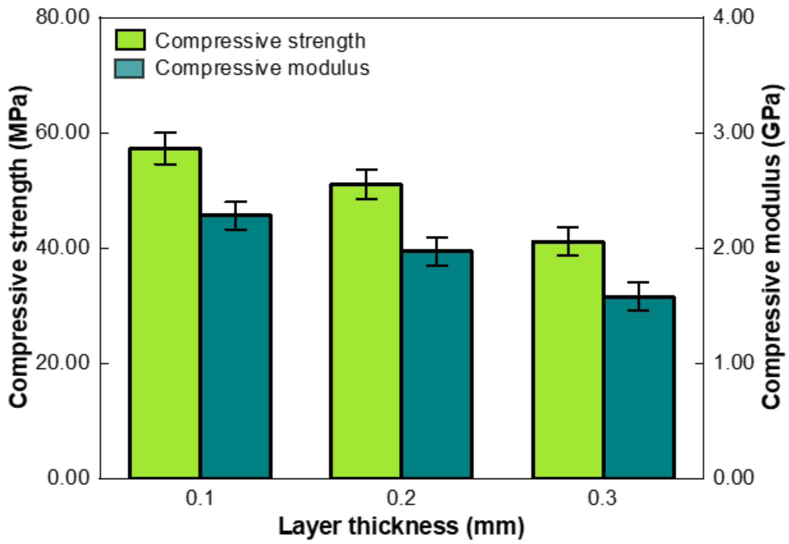

Fig. 2. Effect of layer thickness on the compressive properties of PA models

Effect of Infill Density on the Compressive Properties of PA Models

The layer thickness was set to 0.1 mm and the heated bed temperature to 90 °C. The compressive properties of PA models were tested at different infill densities (30%, 60%, and 90%). As evident from Fig. 3, both the compressive strength and compressive modulus of the PA models progressively increased as the infill density was increased. At lower infill density, the internal support structure of the PA model exhibited a sparse grid pattern, rendering it susceptible to local buckling instability under compression and overall structural collapse. Conversely, as the infill density increased, the support structure of the PA model adopted a dense grid pattern. During compression, it exhibited mechanical behavior similar to a solid model. The failure mode transitioned from instability collapse of the infill structure to overall plastic yielding of the structure. Therefore, increasing the infill density was found to be beneficial for enhancing the compressive properties of PA models.

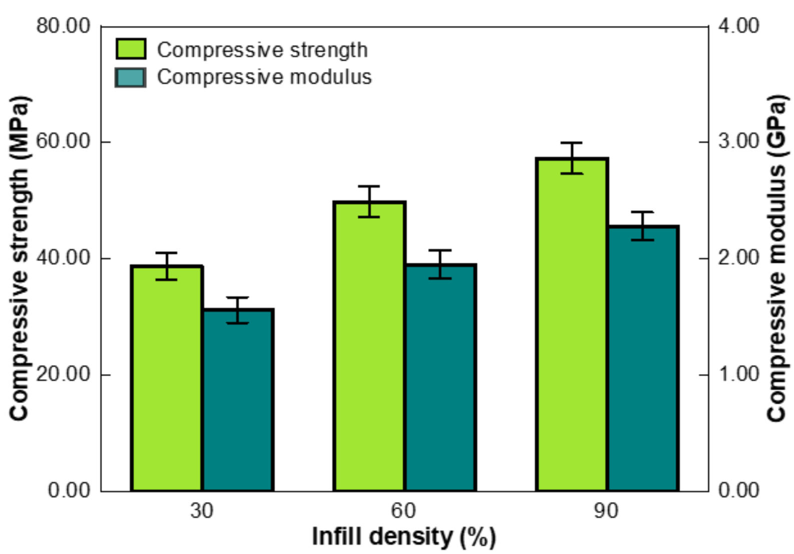

Fig. 3. Effect of infill density on the compressive properties of PA models

Effect of Heated Bed Temperature on the Compressive Properties of PA Models

The layer thickness was set to 0.1 mm and the infill density to 90%. The compressive properties of PA models were tested at different heated bed temperatures (50, 70, and 90 °C), with results shown in Fig. 4. Both the compressive strength and compressive modulus of the PA models progressively increased as the heated bed temperature was increased. This occurred because the molecular chains of the PA melt rearranged from a disordered state into a regular crystalline structure during cooling. This process was accompanied by a high volumetric shrinkage rate, rendering the PA model particularly sensitive to ambient temperature variations (Wang *et al.* 2022). An elevated heated bed temperature enhanced the thermal stability of the printing environment. This slowed the cooling rate of the deposited PA melt and effectively suppressed the accumulation of residual stresses within the model caused by rapid cooling. Under compressive loading, owing to its low internal stresses and favorable interlayer bonding properties, PA models exhibited greater susceptibility to plastic deformation rather than brittle failure characterized by interlayer delamination. Consequently, increasing the heated bed temperature was found to be beneficial for enhancing the compressive properties of PA models.

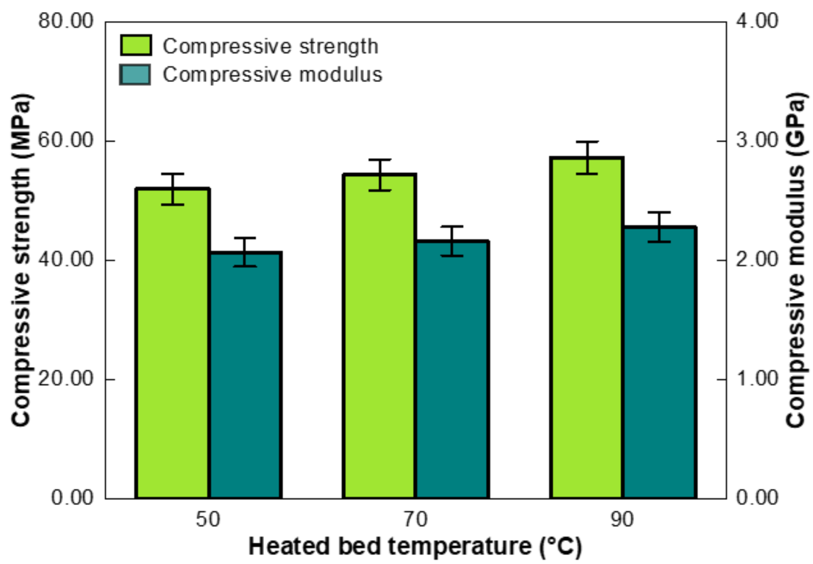

Fig. 4. Effect of heated bed temperature on the compressive properties of PA models

Application Case

This study demonstrated the application through a case involving a toy table for a 3-year-old child (height: 100 cm). Based on anthropometric data indicating that children experience significant growth between ages 2 and 3 (*e.g.*, increases of approximately 7 to 10 cm in stature, 6 to 8 cm in sitting height, and 4 to 6 cm in elbow height), a customized riser was designed and fabricated *via* FDM 3D printing. The original table, designed for 2-year-olds at a height of 38 cm, became ergonomically unsuitable for the older child, causing forward-leaning posture and shoulder strain. To resolve this, the appropriate table height for the 3-year-old was calculated to be 45 cm, requiring a 7 cm elevation. Accordingly, a customized riser was modeled and additively manufactured to achieve this height adjustment.

The furniture risers were fabricated using PA6 filament based on FDM 3D printing. According to the optimized process parameters from the previous section, the settings were as follows: layer thickness (0.1 mm), infill density (90%), heated bed temperature (90 °C), extrusion temperature (230 °C), extrusion flow rate (15 mm³/s), sidewall thickness (0.8 mm), and infill pattern (grid). The furniture risers printed under these parameters exhibit excellent compressive properties and surface finish.

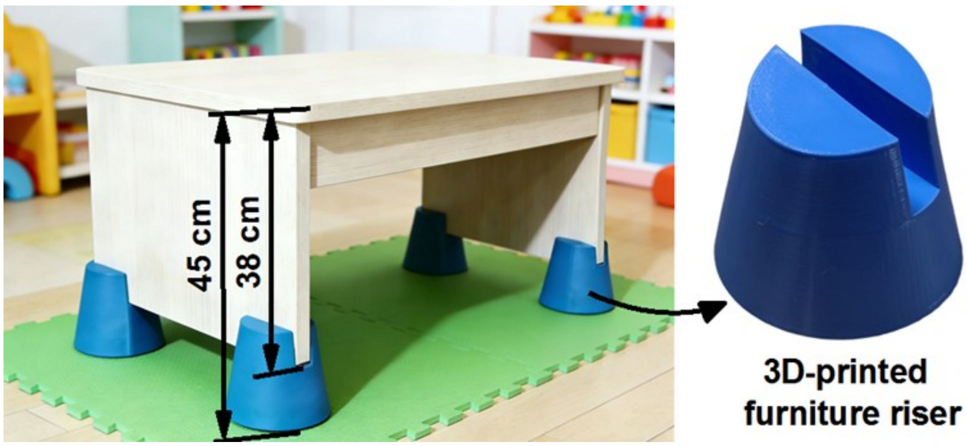

Fig. 5. 3D-printed prototype of furniture riser

The furniture riser was assembled with the side panel of the children's toy table *via* a slotting mechanism (Fig. 5). This design not only allows for rapid adjustment of the table height based on the child's body dimensions, but also offers low cost and high development efficiency. This demonstrates the application value of 3D-printed customized furniture components in promoting healthy child development and resource conservation.

Future Work

The present work considered a technical solution that involved 100% of plastic materials. Alternative approaches of two kinds can be considered for possible future research. On the one hand, it is known that cellulosic particles of various types, sometimes with surface modification, can be used as reinforcement in plastic filaments used in additive manufacturing. In addition, various wood products, including solid wood or engineered wood, could be used in future designs for furniture risers, including risers that have optional height adjustments.

CONCLUSIONS

1. This study analyzed the influence of key process parameters (layer thickness, infill density, and heated bed temperature) on the compressive properties of polyamide (PA) models. The experimental results showed that as the layer thickness was decreased, the infill density increased. As the heated bed temperature was increased, the compressive strength and compressive modulus of the PA model gradually increased, and the compressive properties improved. The optimized process parameters for compressive properties were: layer thickness (0.1 mm), infill density (90%), and heated bed temperature (90 °C).

2. Using PA6 filament as the printing material, furniture risers were designed and 3D-printed based on optimized process parameters. The 3D-printed furniture risers exhibited excellent compressive strength and surface finish and allow for quick height adjustment to accommodate children's varying body sizes. Moreover, the 3D printing approach itself was found to be cost-effective and highly efficient.

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