Analysis of 3D Printing Process Parameters and Applications for Wood-plastic Composite Filaments

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To enhance the forming quality of wood-plastic composite (WPC) models manufactured by fused filament fabrication (FFF) 3D printing, particularly in terms of surface quality and mechanical properties, this study analysed the 3D printing process parameters (layer height, extrusion ratio, and printing speed) for WPC filaments. Through surface roughness and tensile property tests, the optimal combination of process parameters for achieving the best forming quality was determined. Based on the optimized parameters, FFF technology and WPC filament were applied to practice 3D printing of wooden crafts. Experimental results showed that as the layer height decreases, extrusion ratio increases, and printing speed decreases, both the arithmetic average roughness (R_a) and average maximum height (R_z) of the WPC models decreased, leading to a significant improvement in surface quality. Concurrently, the mechanical properties of the WPC models were enhanced due to the increase in ultimate strength and elongation at break. Under the process conditions of 0.1 mm layer height, 110% extrusion ratio, and 20 mm/s printing speed, the printed wooden bowl and spoon exhibited excellent surface quality and favorable mechanical properties, providing a valuable reference for the application of 3D printing in the rapid fabrication of wooden crafts.

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Keywords: Fused filament fabrication; 3D printing; Wood-plastic composite filament; Wooden crafts

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INTRODUCTION

Wood-plastic composite (WPC) filament is a rapidly emerging category of green material in the field of 3D printing. It is primarily made from plant-based fibers or powders (*e.g.*, wood powder or bamboo powder) and thermoplastic polymers (*e.g.*, polylactic acid or polypropylene), which are produced through a process of blending and composite formation followed by melt extrusion (Ding *et al*. 2022). This material combines the natural texture of wood with the excellent processability of plastics, demonstrating broad application potential in areas such as creative home furnishings, architectural decoration, and cultural and creative products (Deng *et al*. 2023). Naturally, WPC filaments and the finished products manufactured from them *via* 3D printing also present certain problems requiring improvement, such as fibre-matrix incompatibility, layer separation, and surface roughness (Chen *et al*. 2022).

Fused filament fabrication (FFF) is one of the most widely used 3D printing technologies today (Han *et al*. 2022). Its process principle is as follows: the feeding mechanism feeds thermoplastic filament into a nozzle, where it is heated and melted into a molten state. The nozzle then moves along a pre-programmed printing path, extruding and depositing the molten material onto the build platform (Feng *et al*. 2022). The extruded material rapidly cools and solidifies, bonding firmly with the previously deposited layer. Through this layer-by-layer accumulation process, a three-dimensional solid model is ultimately constructed (Hu *et al*. 2021).

The application of WPC filaments in manufacturing wooden crafts *via* FFF technology has emerged as a prominent trend in the 3D printing sector in recent years (Li *et al*. 2022). Compared to conventional 3D printing filaments, WPC filaments offer distinct advantages in FFF 3D printing, as follows: (1) 3D-printed WPC models exhibit the natural colour and grain of timber, satisfying consumer demand for organic aesthetics and personalised appearances; (2) The incorporation of wood fibres significantly enhances the mechanical properties of WPC filament (such as tensile ultimate strength and elastic modulus), while also improving thermal stability (Hu *et al*. 2024). This effectively mitigates issues such as warping and cracking during the printing process; (3) WPC filament is derived from renewable resources, utilising recycled plastics and agricultural/forestry waste as raw materials (Li *et al*. 2023). This facilitates resource recycling and aligns more closely with the principles of sustainable development and green manufacturing (Huang *et al*. 2022).

To enhance the forming quality of FFF 3D-printed WPC models, particularly their surface quality and mechanical properties, this study analysed the process parameters of 3D-printed WPC filaments. Three parameters significantly influencing both surface quality and mechanical properties were identified: layer height, extrusion ratio, and printing speed (Liu *et al*. 2021). Through surface roughness and tensile property tests, the optimal process parameters for forming quality were determined. Building upon these optimised parameters, this study applied FFF technology with WPC filament to produce 3D-printed wooden crafts. The finished products exhibited commendable surface quality and mechanical properties, providing valuable reference for the rapid development of similar wooden products.

EXPERIMENTAL

Materials

The WPC filament (Miracle 3D, Suzhou, China) was employed for 3D printing *via* FFF technology. This filament is a wood-plastic composite material composed of pine wood powder and polylactic acid, with a pine wood powder mass fraction of 15%. It possesses a diameter of 1.75 mm, a melting point of 170 °C and a density of 1.25 g/cm³ (Liu *et al*. 2020).

Specimen Preparation

This study employed uniaxial tensile tests to evaluate the mechanical properties of the WPC model. Referencing the dumbbell-shaped specimen specified in ASTM D638-14 (2022), model *A* (as shown in Fig. 1) was designed using SolidWorks software (Education version, Dassault Systemes, Paris, France).

Surface roughness tests were employed to evaluate the surface quality of the WPC model, with model *B* designed using SolidWorks software, as depicted in Fig. 1. Both models *A* and *B* were manufactured using an FFF 3D printer (0.4 mm nozzle diameter, Miracle 3D, Suzhou, China) with standard printing parameters set as follows: printing temperature at 185 °C, infill density at 50%, build platform temperature at 60 °C, shell thickness at 1.2 mm, and retraction distance at 5 mm (Mo *et al*. 2022).

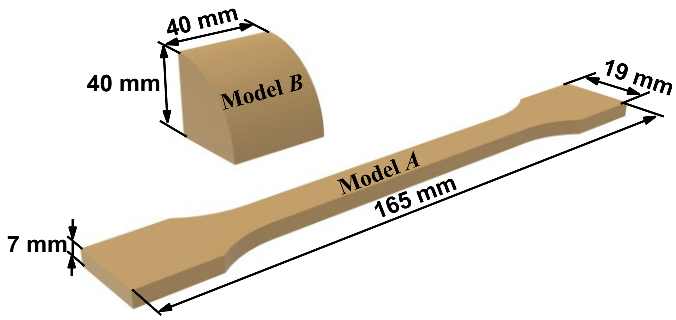

Fig. 1. Schematic diagram of model *A* and *B*

Performance Test

Tensile tests were performed on model *A* using a universal testing machine (AG-X, Shimadzu, Kyoto, Japan) in accordance with the ASTM D638-14 (2022) standard. The tests were conducted under quasi-static loading conditions at a speed of 1 mm/min and an ambient temperature of 20 °C. Two representative parameters (ultimate strength and elongation at break) were adopted as evaluation indicators.

The surface roughness of model *B* was measured using a profilometer (JB-4C, Taiming, Shanghai, China). Because this study focused on evaluating the surface quality of curved structures, roughness measurements were specifically taken on the curved surface of model *B*. Two representative parameters (arithmetic average roughness R_a) and average maximum height R_z) were adopted as evaluation indicators. Measurement points were located at the centre of Model *B*'s curved surfaces, with a measurement length of 0.5 mm.

RESULTS AND DISCUSSION

Effect of Layer Height on the Forming Quality of WPC Models

Under the conditions of 110% extrusion ratio and printing speed of 20 mm/s, the surface quality and mechanical properties of WPC models with three layer heights (0.1, 0.2, and 0.3 mm) were tested. Five samples were tested per group, with results presented in Figs. 2 and 3. As observed in Figs. 2 and 3, within the layer height range of 0.1 to approximately 0.3 mm, as the layer height decreased, both R_a and R_z decreased, leading to an improvement in the surface quality of the models. Concurrently, the mechanical properties of the WPC models were enhanced due to the increase in ultimate strength and elongation at break. This phenomenon can be attributed to two reasons: In terms of surface quality, the reduction in layer height increases the number of layers in the build direction, mitigating the 'stair-step effect' caused by the layer-by-layer deposition nature of fused deposition modeling (FDM) technology, thereby significantly reducing the surface roughness of the models and resulting in a smoother surface finish (Qi *et al*. 2023). In terms of mechanical properties, a smaller layer height results in a thinner extruded melt from the nozzle, which under the same extrusion flow rate, covers a larger spreading area (Wang *et al*. 2023). This promotes remelting and molecular diffusion between the newly deposited layer and the already solidified layers, forming a denser interlayer molecular entanglement network. Consequently, the interlayer bonding strength is enhanced, leading to a significant improvement in the ultimate strength of the models under tensile load.

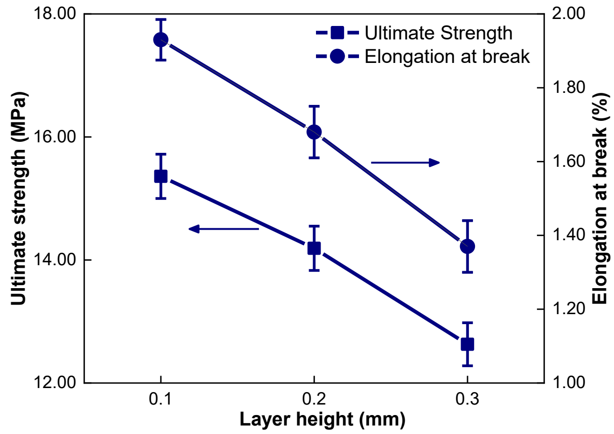

Fig. 2. Effect of layer height on the mechanical properties of WPC models

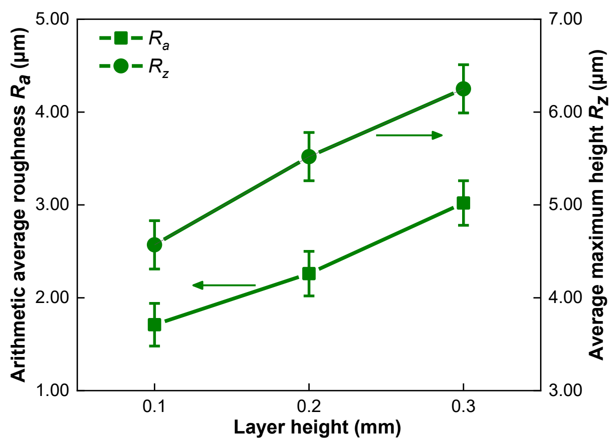

Fig. 3. Effect of layer height on the surface quality of WPC models

Effect of Extrusion Ratio on the Forming Quality of WPC Models

Under the conditions of 0.1 mm layer height and printing speed of 20 mm/s, the surface quality and mechanical properties of WPC models with three extrusion ratios (90%, 100%, and 110%) were tested. Five samples were tested per group, with results presented in Figs. 4 and 5. As observed in Figs. 4 and 5, within the extrusion ratio range of 90 to approximately 110%, as the extrusion ratio increased, both R_a and R_z decreased, leading to an improvement in the surface quality of the models. Concurrently, the mechanical properties of the WPC models were enhanced due to the increase in ultimate strength and elongation at break. During the extrusion of WPC filament, a higher extrusion ratio increased the extrusion flow rate of the melt in the nozzle, effectively avoiding pore defects caused by insufficient melt filling (Wang *et al*. 2022). This resulted in a more continuous, uniform, and smooth deposition path for the melt, thereby significantly reducing the surface roughness of the models. In terms of mechanical properties, the increase in extrusion ratio (extrusion flow rate) led to a higher extrusion pressure in the nozzle, promoting more sufficient melt flow and enhancing the fusion effect between adjacent layer filaments (Yang *et al*. 2022). This improved the interlayer bonding strength. The resulting denser internal structure of the models effectively mitigated stress concentration issues, leading to a significant improvement in the ultimate strength of the models under tensile load.

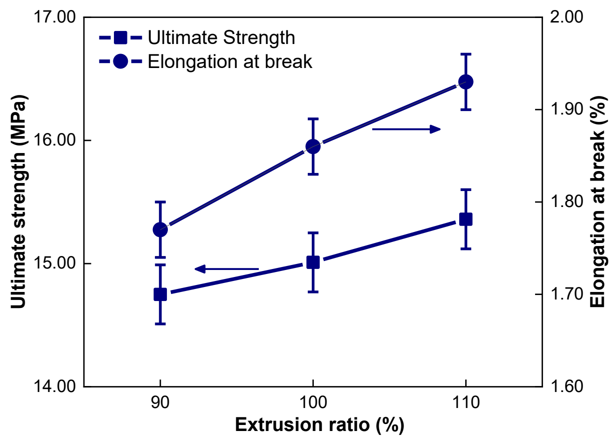

Fig. 4. Effect of extrusion ratio on the mechanical properties of WPC models

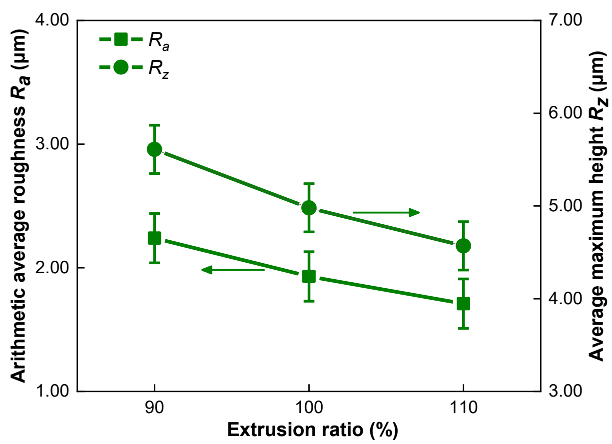

Fig. 5. Effect of extrusion ratio on the surface quality of WPC models

Effect of Printing Speed on the Forming Quality of WPC Models

Under the conditions of 0.1 mm layer height and 110% extrusion ratio, the surface quality and mechanical properties of WPC models at three printing speeds (20, 30, and 40 mm/s) were tested. Five samples were tested per group, with results presented in Figs. 6 and 7. As observed in Figs. 6 and 7, within the printing speed range of 20 to approximately 40 mm/s, as the printing speed decreased, both R_a and R_z decreased, leading to an improvement in the surface quality of the models. Concurrently, the mechanical properties of the WPC models were enhanced due to the increase in ultimate strength and elongation at break. This is because a slower printing speed increased the nozzle's movement time along the deposition path, allowing for a more sufficient and uniform spreading and deposition process of the melt. This effectively reduced defects, such as surface depressions and stringing, caused by melt retraction or insufficient flow, thereby significantly reducing the surface roughness of the models. In terms of mechanical properties, the slower printing speed provided more time for heat conduction and molecular diffusion between the melt and the previously deposited layers (Yu *et al*. 2024). This promotes molecular entanglement at the bonding interface, forming a denser interfacial structure (Zhang *et al*. 2025). As a result, the ultimate strength of the models under tensile load was significantly improved.

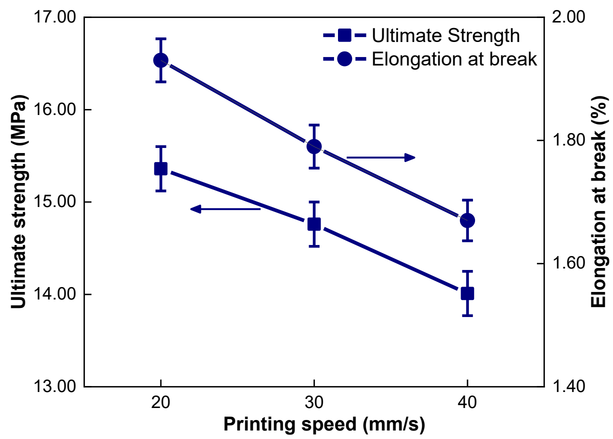

Fig. 6. Effect of printing speed on the mechanical properties of WPC models

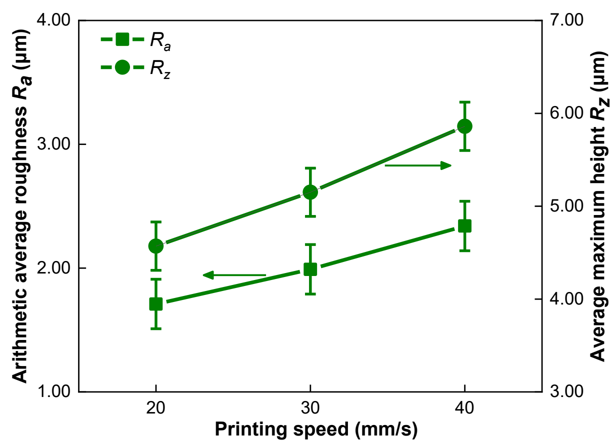

Fig. 7. Effect of printing speed on the surface quality of WPC models

3D PRINTING RAPID PROTOTYPING

Based on FFF technology, the application of WPC filament for the rapid prototyping of wooden crafts through 3D printing represents an innovative attempt to integrate traditional woodworking skills with digital manufacturing. This study focused on a wooden bowl and spoon, conducting practical 3D printing experiments for wooden crafts. In terms of printing process, the optimal parameters determined through experiments were set as follows: layer height at 0.1 mm, extrusion ratio at 110%, and printing speed at 20 mm/s. Additionally, to balance forming quality and material cost, other process parameters were configured as follows: printing temperature at 220 °C, retraction distance at 5 mm, infill density at 50%, and build platform temperature at 60 °C.

During the 3D printing of wooden crafts, the slicing stage often automatically generates supports for models with overhanging structures. If the supports are printed integrally with the model using the same material (WPC filament), although this helps ensure printing stability, it tends to cause material residue at the contact interface during support removal. This significantly increases the surface roughness of the model and compromises the appearance quality and dimensional accuracy of the final product.

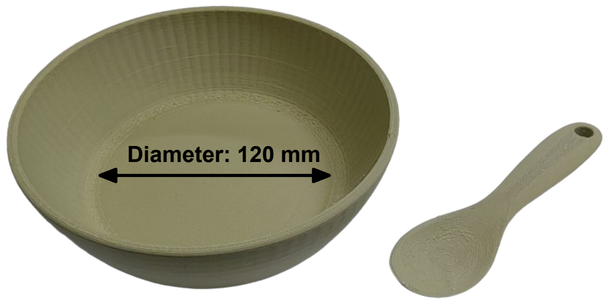

Fig. 8. 3D-printed prototype of the wooden bowl and spoon

To address this issue, this study employed polyvinyl alcohol (PVOH) water-soluble filament as the dedicated printing material for support structures. The PVOH filament exhibited excellent water solubility. After printing, the model with supports only needed to be immersed in warm water for the supports to dissolve completely, eliminating the need for any mechanical removal operations (Zhu *et al*. 2024). This method avoided surface damage and material residue caused by mechanical support removal, thereby improving the forming quality of 3D-printed wooden crafts. The final printed wooden bowl and spoon are shown in Fig. 8.

CONCLUSIONS

1. To enhance the forming quality of wood-polymer composite (WPC) models manufactured by fused filament fabrication (FFF) 3D printing, this study analysed the 3D printing process parameters for WPC filaments. Experimental results showed that as the layer height decreased, extrusion ratio increased, and printing speed decreased, both R_a and R_z decreased, leading to a significant improvement in surface quality. At the same time, mechanical properties were enhanced due to increased ultimate strength and elongation at break.
2. Based on the optimized process parameters (0.1 mm layer height, 110% extrusion ratio, and 20 mm/s printing speed), FFF technology and WPC filament were applied to the 3D printing of wooden crafts. The printed wooden bowl and spoon exhibited excellent surface quality and favorable mechanical properties, providing a valuable reference for the application of 3D printing in the rapid fabrication of wooden crafts.

REFERENCES CITED

ASTM D638-14 (2022). "Standard test method for tensile properties of plastics," ASTM International, West Conshohocken, PA, USA.

Chen, B.-R., Yu, X.-J., and Hu, W.-G. (2022). "Experimental and numerical studies on the cantilevered leg joint and its reinforced version commonly used in modern wood furniture," *BioResources* 17(3), 3952-3964.

https://doi.org/10.15376/biores.17.3.3952-3964
Deng, J.-Z., Huang, N., and Yan, X.-X. (2023). "Effect of composite addition of antibacterial/photochromic/self-repairing microcapsules on the performance of coatings for medium-density fiberboard," *Coatings* 13(11), article 1880. https://doi.org/10.3390/coatings13111880
Ding, T.-T., Yan, X.-X., and Zhao, W.-T. (2022). "Effect of urea–formaldehyde resin–coated colour–change powder microcapsules on performance of waterborne coatings for wood surfaces," *Coatings* 12(9), article 1289. https://doi.org/10.3390/coatings12091289
Feng, X.-H., Yang, Z.-Z., Wang, S.-Q., and Wu, Z.-H. (2022). "The reinforcing effect of lignin-containing cellulose nanofibrils in the methacrylate composites produced by stereolithography," *Polymer Engineering and Science* 2022(9), 2968-2976. https://doi.org/10.1002/pen.26077
Han, Y., Yan, X.-X., and Zhao, W.-T. (2022). "Effect of thermochromic and photo-chromic microcapsules on the surface coating properties for metal substrates," *Coatings* 12(11), article 1642. https://doi.org/10.3390/coatings12111642
Hu, W.-G., Li, S., and Liu, Y. (2021). "Vibrational characteristics of four wood species commonly used in wood products," *BioResources* 16(4), 7101-7111. https://doi.org/10.15376/biores.16.4.7101-7111
Hu, W.-G., Zhao, Y., Xu, W., and Liu, Y.-Q. (2024). "The influences of selected factors on bending moment capacity of case furniture joints," *Applied Sciences* 14(21), article 10044. https://doi.org/10.3390/app142110044
Huang, N., Yan, X.-X., and Zhao, W.-T. (2022). "Influence of photochromic microcapsules on properties of waterborne coating on wood and metal substrates," *Coatings* 12(11), article 1750. https://doi.org/10.3390/coatings12111750
Li, S., and Hu, W.-G. (2023). "Study on mechanical strength of cantilever handrail joints for chair," *BioResources* 18(1), 209-219. https://doi.org/10.15376/biores.18.1.209-219
Li, W.-B., Yan, X.-X., and Zhao, W.-T. (2022). "Preparation of crystal violet lactone complex and its effect on discoloration of metal surface coating," *Polymers* 14(20), article 4443. https://doi.org/10.3390/polym14204443
Liu, Q., Gu, Y., Xu, W., Lu, T., Li, W., and Fan, H. (2021). "Compressive properties of green velvet material used in mattress bedding," *Applied Sciences* 11(23), article 11159. https://doi.org/10.3390/app112311159
Liu, Y., Hu, J., and Wu, Z.-H. (2020). "Fabrication of coatings with structural color on a wood surface," *Coatings* 10(1), article 32. https://doi.org/10.3390/coatings10010032
Mo, X.-F., Zhang, X.-H., Fang, L., and Zhang, Y. (2022). "Research progress of wood-based panels made of thermoplastics as wood adhesives," *Polymers* 14(1), article 98. https://doi.org/10.3390/polym14010098
Qi, Y.-Q., Sun, Y., Zhou, Z.-W., Huang, Y., Li, J.-X, and Liu, G.-Y. (2023). "Response surface optimization based on freeze-thaw cycle pretreatment of poplar wood dyeing effect," *Wood Research* 68(2), 293-305. https://doi.org/10.37763/wr.1336-4561/68.2.293305
Wang, L., Han, Y., and Yan, X.-X. (2022). "Effects of adding methods of fluorane microcapsules and shellac resin microcapsules on the preparation and properties of bifunctional waterborne coatings for basswood," *Polymers* 14(18), article 3919. https://doi.org/10.3390/polym14183919

Wang, Q., Feng, X.-H., and Liu, X.-Y. (2023). "Functionalization of nanocellulose using atom transfer radical polymerization and applications: A review," *Cellulose* 30, 8495-8537. https://doi.org/10.1007/s10570-023-05403-5

Yang, Z.-Z., Feng, X.-H., Xu, M., and Rodrigue, D. (2022). "Printability and properties of 3D printed poplar fiber/polylactic acid biocomposites," *BioResources* 16(2), 2774-2788. https://doi.org/10.15376/biores.16.2.2774-2788

Yu, S.-L., and Wu, Z.-H. (2024). "Research on the influence mechanism of short video communication effect of furniture brand: Based on ELM model and regression analysis," *BioResources* 19(2), 3191-3207. https://doi.org/10.15376/biores.19.2.3191-3207

Zhang, W.-J., Zou, Y.-M., Yan, X.-X., and Li, J. (2025). "Influence of two types of microcapsule composites on the performance of thermochromic UV coatings on bleached poplar wood surfaces," *Coatings* 15(9), article 1001. https://doi.org/10.3390/coatings15091001

Zhu, Y., Wang, Y., and Yan, X.-X. (2024). "Preparation of chitosan-coated *Toddalia asiatica* (L.) lam extract microcapsules and its effect on coating antibacterial properties," *Coatings* 14(8), article 942. https://doi.org/10.3390/coatings14080942

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