

Application Of FDM-Printed PLA Patterns In Investment Casting Using AL9-1 Aluminum Alloy

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Abstract: This article explores the application of Fused Deposition Modeling (FDM) technology using polylactic acid (PLA) for the fabrication of sacrificial patterns within the investment casting process (Lost Pattern Casting). A comprehensive assessment was carried out on the mechanical properties and dimensional accuracy of castings made from AL9-1 aluminum alloy. 3D-printed models served as expendable patterns for creating gypsum-based ceramic molds. The geometric accuracy, surface roughness, and mechanical properties of the alloy after casting were evaluated. It was determined that the proposed approach enables dimensional tolerances of up to ± 0.2 mm and surface roughness of approximately $Ra \approx 12 \mu\text{m}$, without the formation of cracks in the mold. The results confirm the feasibility of using FDM printing in foundry technology for the production of small-batch and prototype parts.

Keywords: FDM, investment casting, PLA, gypsum mold, AL9-1 aluminum alloy, additive manufacturing, 3D printing, Ra, accuracy.

INTRODUCTION:

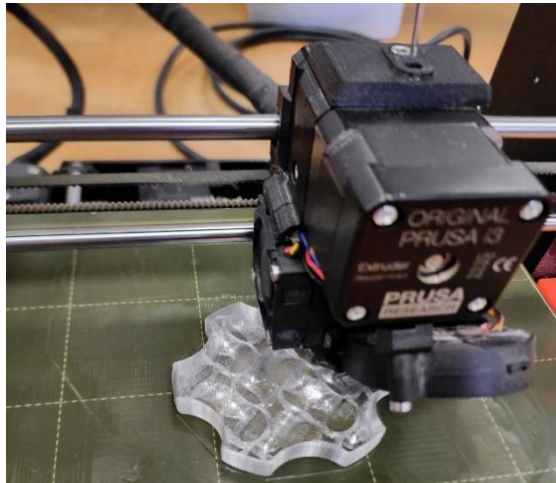
The investment casting method traditionally involves the use of wax or polystyrene patterns, which requires complex tooling and equipment. With the development of additive manufacturing technologies, it has become possible to use 3D printing with thermoplastics, particularly PLA, as an alternative to conventional patterns. The key advantages are rapid prototyping and the elimination of costly tooling.

The objective of this study is to evaluate the technological feasibility of using PLA patterns, produced by FDM printing, as expendable templates for the creation of ceramic-gypsum molds intended

for casting AL9-1 aluminum alloy. The quality of the resulting castings was assessed based on key metrics: dimensional accuracy, surface roughness, and mechanical performance.

METHODS

PLA filament was used as the base material. The models were designed in SolidWorks and printed using an Original Prusa i3 printer with the following parameters: 0.4 mm nozzle diameter, 0.15 mm layer height, 20% infill, and a print speed of 30 mm/s. Two types of geometry were selected: a simple plate and a valve body housing.



**Figure 1. 3D printing of the PLA pattern on an Original Prusa i3.
(Insert photo of the model being printed.)**

After printing, the models underwent surface smoothing using short-term exposure to dichloromethane vapor, followed by localized reinforcement with wax for the gating system. The mold shell was formed from a mixture of gypsum, quartz sand, and water in a mass ratio of 2.5:0.5:0.7. After 24 hours of curing, the mold was calcined at 300 °C for 3 hours to ensure complete burnout of the

PLA.

The molten metal was poured vertically at a temperature of 820 °C using AL9-1 aluminum alloy (Al-7Si-0.3Mg-0.1Ti). After cooling, the mold was broken, the casting was extracted, and post-processing steps such as gate removal, grinding, and dimensional inspection were performed.



**Figure 2. Final aluminum casting with gating system and feeder.
(Insert photo of the finished casting after mold removal.)**

The resulting casting, as shown in the figure, includes the gating system, central component, and a massive feeder. Structural analysis revealed uniform mold filling, indicating adequate permeability of the gypsum shell during metal pouring. However, shrinkage defects and initial signs of porosity were observed at the top of the feeder, likely due to

insufficient thermal resistance of the mold and localized overheating during the pour.

A visual and tactile inspection confirmed satisfactory surface cleanliness—surface roughness was minimal, and the structure was uniform with no evidence of incomplete filling. Some areas exhibited delamination of the mold shell, attributed to excessive thermal

gradients between the molten metal and the ceramic mold. These zones could be subjects of future studies into thermal stresses and mold behavior under high-temperature loads.

The results confirmed the technological viability of the process and helped identify potential improvements in thermal control and molding compound composition.

RESULTS

Surface roughness measured at control zones ranged from 12 to 14 $\mu\text{m Ra}$, which meets the acceptable standards for investment casting. Dimensional inspection using a 3D scanner showed deviations from the CAD model not exceeding $\pm 0.2\text{ mm}$ over 90% of the surface area.

Mechanical tests conducted on a tensile testing machine in accordance with GOST 1497-84 yielded the following results:

- Ultimate tensile strength: 174 MPa
- Yield strength: 96.3 MPa
- Elongation at break: 2.9%

Microstructural analysis using optical microscopy revealed a uniform fine-grained structure, consisting of eutectic silicon and primary aluminum α -crystals. No mold breakage was observed, indicating sufficient thermal resistance and adhesion between the gypsum mold and the PLA pattern.

DISCUSSION

The use of PLA models produced via FDM printing in foundry applications offers several advantages: high dimensional accuracy, no need for dedicated tooling, and environmental safety during burnout. Despite the inherent porosity of printed models and their stepped surface texture, shell adhesion proved sufficient, preventing cracking during metal pouring.

The observed reduction in elongation compared to castings in sand molds is attributed to the higher cooling rate and increased microporosity in the solidified structure. To enhance material properties, subsequent T6 heat treatment (solution treatment and aging) is recommended.

CONCLUSION

FDM printing of PLA patterns is a viable method for investment casting. The resulting castings meet industrial prototyping requirements in terms of accuracy, surface finish, and mechanical properties. The approach is particularly effective for low-volume or custom production of complex parts.

Future research will involve expanding the range of pattern geometries, comparing PLA with alternative

printable materials such as PVB and polystyrene, and introducing centrifugal or vacuum casting techniques to improve mold filling quality.

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