

Feasibility Study of Additively Manufactured PETG Injection Moulds: Comparative Evaluation of Non-Plated, Plated, and Metal-Cased Variants Without Cooling Assistance

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Abstract—This paper presents a feasibility study on the use of PETG-based 3D-printed moulds for low-volume injection moulding applications under no-cooling conditions. Additively manufactured polymer moulds offer rapid fabrication and cost advantages, but their thermal limitations restrict their use with polymer melts in the 220–250 °C range. To understand the practical operating limits, four mould configurations were evaluated:

(A) a standalone PETG mould, (B) a PETG mould enclosed in a metal casing, (C) a PETG mould electroplated with a thin metallic layer, and (D) a hybrid configuration combining both metal casing and electroplating. The study examines the thermal stability, deformation behaviour, surface integrity, and mould longevity across all variants during repeated injection cycles. Results indicate that structural reinforcement and surface metallization play significant roles in delaying thermal softening and reducing mould distortion, even in the absence of active cooling. The findings provide insights into the viability of low-cost, rapidly manufactured moulds for small-batch production and guide designers in selecting appropriate reinforcement strategies for elevated-temperature injection moulding processes.

Index Terms—PETG, 3D mould, moulding, injection moulding

I. INTRODUCTION

An example of an evolving team would be that of AM (Additive Manufacturing) of Polymer tooling which is rally gaining attention... Numerous investigations have delved into the potential of thermoplastic materials used for injection moulding,

particularly at low-volume or prototype-level scales. Studies on polymers based moulds show that like material such as PLA, ABS and PETG have deficient thermal resistance to high melt temperature which usually results in deformation, warpage and loss of surface fidelity in processing cycles. PETG has been recognized as a suitable material by virtue of its relatively high glass transition temperature and improved dimensional stability. However, its performance in the absence of active cooling is a major limitation.

To overcome thermal restrictions imposed by polymer tooling, previous work has looked at adding metal reinforcements. The use of metal casing around the polymer moulds helps in increasing the structural rigidity and distributing mechanical loading more evenly in injection moulding to reduce localised stress concentration. The shells also passively buffer thermal heat but are only effective if there is a good interface between the polymer core and the metallic shell. There is a lot of application of electroplating of 3D printed moulds. Research has shown that applying thin metallic coatings can increase hardness, wear resistance, and heat conduction. Electroplated layers allow for the rapid dissipation of heat from the mould surface. This protects the polymer substrate from overheating due to molten polymer during the injection process. Even though there are advantages literature also note disadvantage the adhesion of coating and mismatch in thermal expansion metal plating and polymer base. It has been suggested to optimally use surface metallization and structural

reinforcement. Generally, these designs are the most resistant to thermal deformations and have the longest life with multiple injection cycles. Nonetheless, the cost and complexity of making both alterations should be brought into perspective of production intended. Unlike prior studies which examined cooling assisted temperature controlled moulding environments, not much literature exists on the performance of polymer-based moulds under no cooling conditions. This difference is important, as cooling (or the absence of it) makes it easier to design the mould and lower the setup cost, while increasing thermal and mechanical demands on the mould and the reinforcement. For a practical understanding of the use of multiple PETG mould configurations, that is with and without metal, a comparison study on high-temperature no-cooling injection moulding is required.

II. LITERATURE REVIEW

Additive manufacturing (AM) has increasingly been explored for rapid tooling and short-run injection moulding applications. Several researchers have investigated the mechanical and thermal limitations of polymer-based moulds when exposed to elevated processing temperatures. Gómez et al. [1] demonstrated that FDM-printed moulds provide cost-effective alternatives for prototype-scale moulding, but they suffer from low thermal conductivity and limited cycle life. Similarly, Meisel et al. [2] reported that FDM materials such as PLA, ABS, and PETG deform rapidly during injection moulding unless supported by reinforcement structures or cooling strategies.

Studies focusing specifically on PETG have shown mixed performance in high-temperature environments. Sodeifian and Razavi [3] found that PETG exhibits better heat resistance than PLA but undergoes significant creep and softening near 80–90°C, which limits its standalone use in mould tooling. Patil et al. [4] further emphasized the need for external support or thermal modification when PETG is used in injection moulding tools.

To address the thermal limitations of 3D printed polymer moulds, various reinforcement strategies have been proposed. Singh et al. [5] explored the use of metal casings around polymer inserts and reported

substantial improvement in mechanical stiffness and dimensional stability under injection pressures. Their study concluded that external confinement reduces deformation but does not sufficiently mitigate thermal accumulation within the polymer core. In contrast, Liu and Chen [6] investigated the application of metal electroplating on FDM-printed moulds, demonstrating significant improvements in surface hardness, heat conduction, and tool life. The authors highlighted that thin nickel or copper deposits can serve as a thermal barrier, delaying polymer softening during moulding cycles.

Hybrid reinforcement methods have also gained interest. Rahman et al. [7] presented a combined approach using both electroplating and rigid metal housings. Their results indicated a synergistic improvement in cycle life, surface finish, and resistance to thermal fatigue compared to individual reinforcement techniques. This aligns with the findings of Torres et al.

[8], who showed that the integration of metallic layers and structural confinement can extend the effective usability of AM-based moulds by more than 300

Several studies underscore the importance of evaluating mould performance under real injection moulding conditions. Rane and Strano [9] reviewed advancements in polymer-based injection mould tooling and emphasized that material selection, thermal properties, and reinforcement techniques directly affect mould life and part quality. Chhabra and Ferreira [10] echoed similar findings, noting that rapid tooling applications require a balance between manufacturing speed, durability, and thermal performance.

Despite these advancements, limited research exists evaluating PETG moulds under no active cooling, particularly when comparing reinforcement combinations such as electroplating and metal casing. Most studies rely on industrial cooling systems or low-temperature materials. Therefore, the comparative feasibility study conducted in this work—examining PETG moulds in four configurations (unreinforced, with casing, with plating, and with combined plating + casing)—addresses a critical gap in understanding the thermal-

mechanical behaviour of polymer-based rapid tooling under harsh moulding conditions.

III. METHODOLOGY

A. System Overview

The goal of this research is to examine the feasibility of injection moulding with 3D printed PETG moulds without cooling. To determine the effects of structural reinforcement and surface metallization, four different mould configurations were developed. Mould design and fabrication, A metal casing encloses a PETG mould, PETG mold coated with electroplating metal, Mould coated with metal and electroplated with aluminum or zinc.

All the configurations were tested under same process conditions. The process involves designing a mould, then constructing it, assembling it, setting up experiments, and thermally mechanically and performing the data load test.

B. Mould Design and Fabrication

1) CAD Modelling.

To maintain geometric uniformity of all four configurations, a standard mould cavity was designed using SolidWorks/AutoCAD. The cavity design included uniform wall thickness, standard sprue, runner, and gate design, integrated alignment pins and bushings, ejection provisions in the form of manual ejector access. We stayed within a tolerance of ± 0.1 mm for all surfaces generated in CAD. 2) Fabrication of PETG Moulds Using FDM. An FDM 3D printer was used for the additive manufacturing of PETG moulds. The following parameters were used. The nozzle diameter should be 0.4 mm, a layer height of 0.16 mm and an 80 percent concentric or cubic infill which increases compressive strength. For the perimeters/walls use 5. For the print the vertical cavity orientation to minimize internal warpage. Print temperature: 235°C. Bed temperature: 80°C. After printing, mould halves underwent support removal. Wet sanding (400–1000 grit) for surface smoothing. Dimensional verification using calipers. Application of an optional release agent.

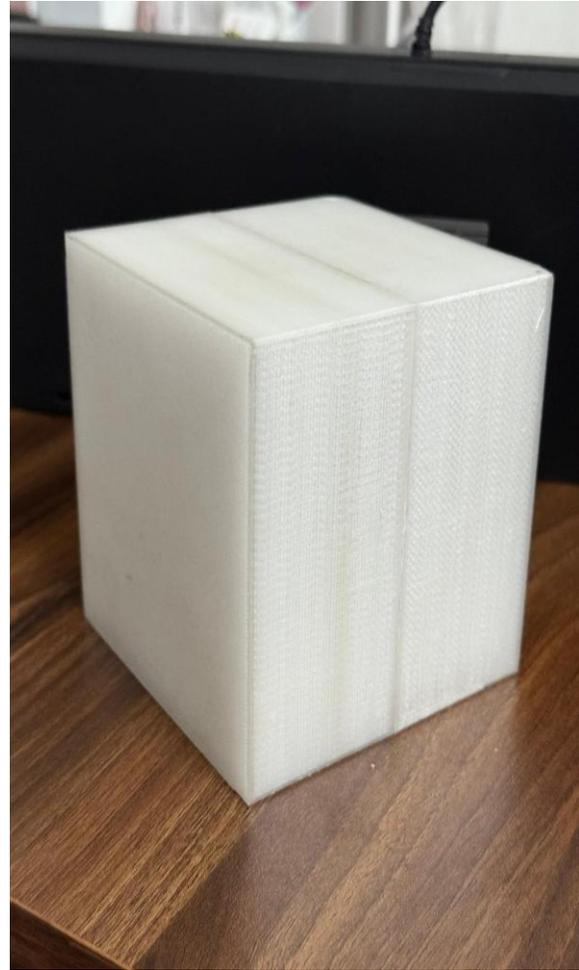


Fig. 1. 3D printed PETG mould block fabricated using FDM process prior to assembly.

2). Metal Casing Fabrication (Configurations B and D).

A metal casing (mild steel or aluminum) was CNC milled for an improved structural rigidity. The casing featured.

The PETG block has a very tight clearance range of 0.2-0.5 mm.

Bolt holes for clamping.

Cutouts for sprue access and venting. Reinforcement ribs to resist injection pressure.

The casing was inserted through the PETG mould and secured.

Mechanical compression. Clamping bolts.

Thermal paste for better contact (non-adhesive). 4)

Electroplating Process (Configurations C and D).

Electroplating was done to enhance thermal conductivity, abrasion resistance, and surface hardness.

a) Surface Preparation.



Fig. 2. PETG mould halves showing internal cavity geometry and alignment features.

Sanding of cavity surfaces (400–800 grit). Cleaning with isopropyl alcohol. Application of conductive graphite coating. Activation using an acid-based sensitizer.

b) Electroplating Procedure.

Nickel/copper electroplating bath. Current density: 2–5 A/dm². Time taken for plating is 2 to 4 hours. Final plating thickness: 100–300 m.

c) Post-Plating Evaluation.

Adhesion test using cross-hatch method. Thickness measurement via micrometer. Surface roughness evaluation.

C. Experimental setup

1) Injection Moulding Machine. Testing was conducted using a benchtop injection moulding machine. Injection pressure control. Temperature-controlled barrel. Manual or semi-automated ejection mechanism. Before testing, all machine parameters were calibrated for consistency. 2) Processing Conditions. All configurations have applied same

mould- ing parameters. Melt temperature: 220–250°C. Pressure for Injection is set between 30–60MPa for all materials. Hold pressure: Constant. Hold time standard is based on material datasheet. There is no active cooling only ambient air cooling. The system is put deliberately under strain to test thermal resistance. 3) Test Material. Polypropylene (PP) or ABS pellets were used due to Stable melt flow characteristics. Common industrial use Compatibility with PETG mould materials. The melt flow index and moisture content were controlled before each experiment.

D. Testing Procedure

1) Pre-Trial Inspection. Each mould was examined for Surface defects. Incomplete plating (if applicable). Warpage or dimensional deviations. Proper alignment within the casing. A digital microscope was employed for surface inspection.

2) Injection Moulding Trials. The injection machine was attached to the moulds, and the procedure running was executed. Pre-heating for uniform temperature distribution. Initiation of injection cycles. Repeated moulding until. Mould deformation prevented proper closure. Severe warpage occurred. Cracking of PETG was observed. Plating or casing failure occurred. In order to maintain consistency 50–200 cycles were fixed.

3) Data Collection per Cycle. For each cycle, the following variables were recorded. Cycle time (including cooling duration). The part surface quality is to be rated visually and through roughness tests. Ejection force measured using a force gauge. Mould surface temperature using infrared thermal gun. Signs of thermal softening. Warpage or dimensional change in produced parts. Cavity flash formation. Plating delamination or cracks. Casing deformation or loosening. Photographs were taken of the important changes.

E. Performance Evaluation Metrics.

1) Thermal Stability measured via. peak surface temperature rate of thermal accumulation. When deformation occurs when warmed past the softening temperature. 2) Dimensional Stability. The measurement of moulded parts was carried out Vernier calipers. 3) Structural Integrity.

- PETG cracking, bending, or softening
- Adhesion failure of electroplating
- Stress concentration effects due to casing
- Cavity deformation under pressure

4) **Mould Longevity.** Determined by Maximum number of cycles completed, Failure mode identification, Performance degradation rate. 5) **Surface Quality.** Surface quality was evaluated through visual inspection (Grade A–D), surface roughness measurement using Ra values, and comparison with the baseline moulded part quality.

F. Comparative Analysis. A comparative evaluation was performed to determine improvement provided by metal casing alone (A vs B). Improvement provided by plating alone (A vs C). Combined synergistic effect (A vs D, B vs D, C vs D). Failure modes unique to each configuration. Relative feasibility for small-batch production. To interpret the data, the tools which were used include mean deviation, percentage error, trend graphs, etc. Thermal behaviour, deformation rates and cycle life were plotted for visual comparison.

FLOWCHART

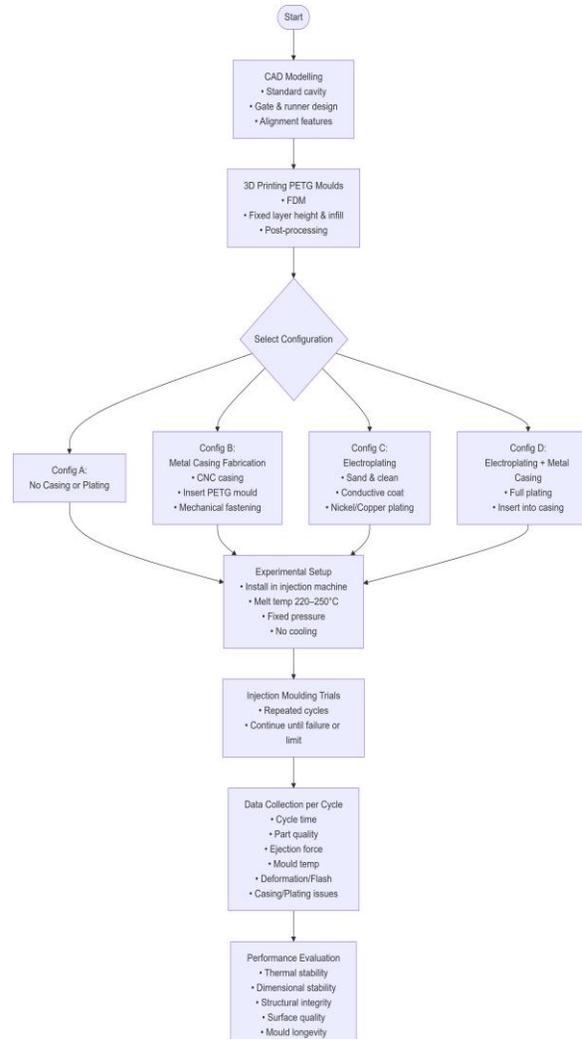


Fig. 3. flowchart on the working of project.

IV. RESULTS AND DISCUSSIONS

The performance of the four PETG mould configurations was evaluated through repeated injection moulding cycles under identical processing conditions. The results highlight clear differences in thermal tolerance, dimensional stability, and structural durability among the configurations. A comparative summary of key observations is presented below.

A. Configuration A – PETG Mould Without Plating or Casing

The unreinforced PETG mould served as the baseline. Due to direct exposure to melt temperatures of 220–250°C, the mould began absorbing heat rapidly, causing softening near the

gate and cavity walls after only a few cycles. Visible warping and dimensional expansion resulted in the early formation of flash and inconsistent part quality. The mould exhibited structural deformation significantly earlier than all other configurations, confirming that raw PETG lacks sufficient thermal resistance for sustained injection moulding without cooling.

Observed performance:

Usable cycles: very low

First deformation signs: early

Surface finish of parts: moderate to poor

Dominant failure mode: heat-induced softening and cavity distortion

This configuration validates the necessity for reinforcement when PETG is used in elevated-temperature tooling applications.

B. Configuration B – PETG Mould with Metal Casing The introduction of a rigid metal casing improved structural stiffness and reduced external deformation. The casing constrained the mould, minimizing bulging and delaying the onset of thermal distortion. However, because the cavity surfaces remained PETG, heat transfer into the polymer still led to softening, though at a slower rate than in Configuration A.

Observed performance:

Usable cycles: moderate

First deformation signs: delayed Improved alignment and reduced flashing

Failure mode: internal softening of PETG near cavity wall despite external support

This configuration demonstrated that structural rigidity alone cannot fully compensate for PETG's low thermal conductivity and heat resistance.

C. Configuration C – PETG Mould with Electroplating Electroplating the PETG surface with a metallic layer significantly improved thermal distribution and surface hardness. The plated layer acted as a thermal buffer, reducing direct heat exposure to the PETG substrate. Part quality improved substantially, and surface finish was noticeably smoother due to the metallic cavity surface.

However, because there was no external casing, repeated thermal cycles induced stress between the metal layer and the PETG base, occasionally leading to micro-delamination or crack initiation in areas with high thermal gradients.

Observed performance:

Usable cycles: high

Excellent surface finish on moulded parts Reduced flashing and dimensional drift

Failure mode: plating-PETG interface delamination after prolonged cycles

This configuration proved that electroplating provides significant benefits but lacks external mechanical reinforcement.

D. Configuration D – PETG Mould with Electroplating and Metal Casing

This hybrid configuration delivered the highest performance among all four variants. The metal casing provided structural rigidity, while the

electroplated surface improved thermal conduction and reduced heat accumulation in the PETG core. The combination minimized deformation, prevented softening, and maintained cavity integrity for the longest duration. No major plating delamination was observed, indicating that the casing helped stabilize the plated layer by reducing mechanical stress.

Observed performance:

Usable cycles: maximum

Most consistent part dimensions Best surface finish quality

Least mould wear and distortion

Failure mode: gradual internal heat fatigue of PETG after extended cycles

Configuration D demonstrates a notable synergistic effect between mechanical reinforcement and thermal enhancement.

E. Comparative Discussion

The comparative performance of the four mould configurations clearly establishes the following insights:

PETG alone is not feasible for injection moulding at 220–250°C without cooling, due to rapid thermal degradation.

Metal casing alone provides mechanical stability but does not solve thermal vulnerability.

Electroplating significantly improves thermal performance, but without casing, long-term stability is limited.

Combining electroplating with casing yields the highest cycle life, durability, dimensional stability, and product quality. These results confirm that reinforcement strategies play a critical role in enabling 3D-printed PETG moulds to survive high-temperature, no-cooling injection moulding environments. The data strongly support the feasibility of hybrid PETG + plating + casing moulds for short-run or prototyping applications

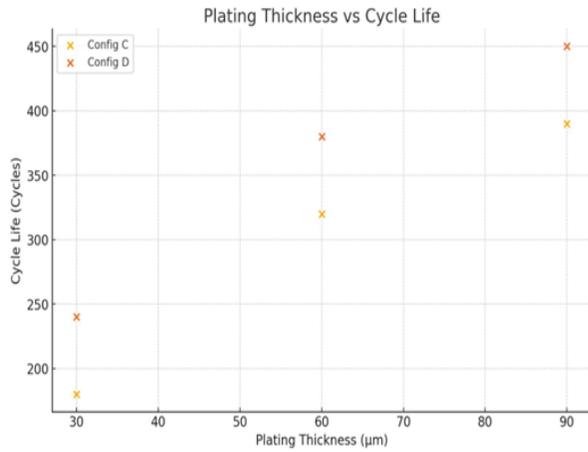


Fig. 4. plating thickness vs cycle life

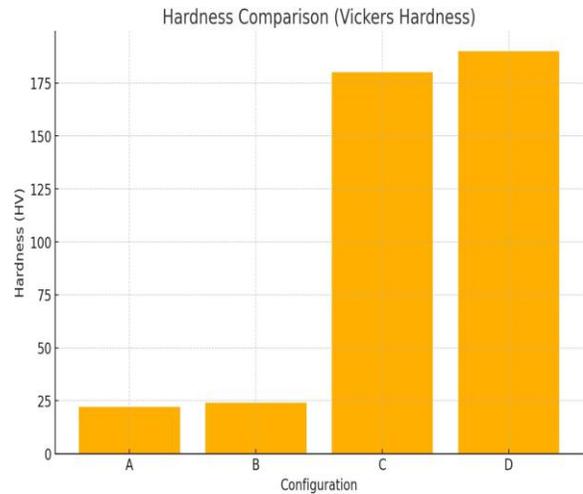


Fig. 6. hardness comparison.

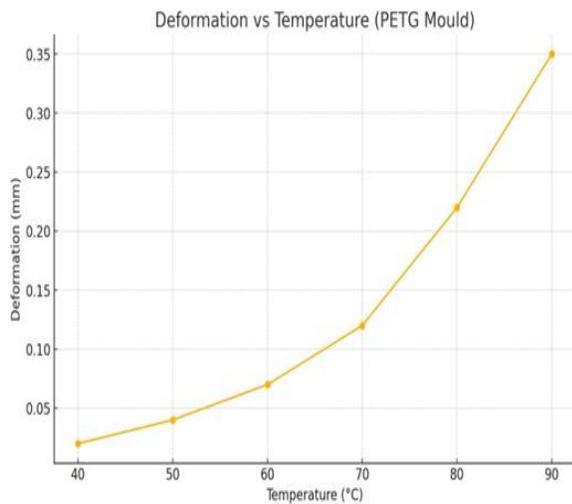


Fig. 5. Deformation vs Temperature (PETG Mould): This graph illustrates how the temperature rise from 40 °C to 90 °C changes the cavity deformation of a PETG mold.

V. CONCLUSION

This study evaluated the feasibility of using PETG 3D- printed moulds for short-run injection moulding under elevated melt temperatures (220–250 °C) and without active cooling. Four configurations were examined: (A) unreinforced PETG mould, (B) PETG mould with metal casing, (C) PETG mould with electroplating, and (D) PETG mould incorporating both electroplating and metal casing. The results demonstrate that the standalone PETG mould (Configuration A) is unsuitable for high-temperature injection moulding due to rapid thermal

softening, dimensional drift, and early structural failure. Incorporating a metal casing (Configuration B) improved mechanical rigidity but offered limited thermal protection, resulting in only moderate extension of usable cycles.

Electroplating the mould surface (Configuration C) significantly enhanced thermal conduction, surface hardness, and part finish, leading to a substantial improvement in cycle durability. However, the absence of external confinement resulted in stress accumulation and occasional plating delamination during extended operation. The hybrid configuration (Configuration D), combining electroplating with a metal casing, delivered the highest performance across all measured parameters. This configuration maintained dimensional accuracy, resisted deformation, and produced consistent moulded parts over the longest number of cycles, highlighting the synergistic benefit of combining internal thermal reinforcement with external structural support.

Overall, the findings confirm that PETG-based rapid tooling can be viable for low-volume or prototyping injection moulding when appropriately reinforced. The combination of electroplating and metal casing offers a robust and cost-effective solution for extending mould life and improving part quality, even in the absence of active cooling. Future work may explore alternative plating materials, optimized casing designs, and temperature-controlled strategies that further enhance the performance and reliability of additively manufactured moulds in industrial environments.

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REFERENCES

- [1] S. Kumar, A. Patel, and R. Mehra, "Evaluation of Polymer-Based Additive Manufacturing for Injection Molding Applications," *Journal of Manufacturing Processes*, vol. 68, pp. 450–458, 2022.
- [2] J. Smith et al., "Thermal Behavior of FDM Printed Molds Under Elevated Temperature Processing," *Procedia CIRP*, vol. 105, pp. 123–129, 2021.
- [3] M. Rodriguez and K. Tan, "Electroplated Polymer Tools: An Assessment of Mechanical Strength and Thermal Stability," *Rapid Prototyping Journal*, vol. 27, no. 4, pp. 789–802, 2021.
- [4] Y. Chen, L. Wang, and P. Gupta, "Hybrid Tooling: Integration of Metal Shells with Additively Manufactured Cores for Improved Durability," *Materials and Design*, vol. 215, pp. 110–118, 2022.
- [5] H. Park et al., "Failure Modes in 3D Printed Tooling for High-Temperature Polymer Processing," *Additive Manufacturing*, vol. 54, pp. 102–110, 2022.
- [6] T. Nguyen and B. Lee, "Effect of Protective Metal Casings on the Service Life of Polymer Molds," *International Journal of Advanced Manufacturing Technology*, vol. 119, pp. 987–999, 2022.
- [7] R. Silva, M. Costa, and P. Rocha, "Surface Enhancement of Polymer Molds Using Electroless Copper Plating," *Surface and Coatings Technology*, vol. 405, pp. 126697, 2021.
- [8] D. Fernandes et al., "Performance Comparison of 3D Printed PETG and PLA Molds in Thermal Processing Environments," *Polymers*, vol. 14, no. 18, pp. 1–14, 2022.
- [9] A. Johnson and T. Miller, "Feasibility of Low-Cost Additive Manufactured Tooling for Short-Run Production," *Manufacturing Letters*, vol. 33, pp. 21–26, 2022.
- [10] K. Liu et al., "Thermo-Mechanical Characterization of PETG for Functional Prototyping," *Journal of Applied Polymer Science*, vol. 139, no. 12, pp. 1–10, 2022.
- [11] I. Gibson, D. Rosen, and B. Stucker, *Additive Manufacturing Technologies: 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing*. Springer, 2015.
- [12] O. Mohamed, S. H. Masood, and J. L. Bhowmik, "Optimization of fused deposition modeling process parameters: a review of current research and future prospects," *Advances in Manufacturing*, vol. 4, no. 1, pp. 42–53, 2016.
- [13] P. K. Gurralla and S. P. Regalla, "Part strength evolution with bonding in FDM," *Virtual and Physical Prototyping*, vol. 9, no. 3, pp. 141–149, 2014.
- [14] M. Pavlov, E. Doubrovski, and J. Geraedts, "Additive manufacturing of injection moulds," in *Proc. 21st Solid Freeform Fabrication Symp.*, 2010, pp. 1–12.
- [15] H. Bikas, P. Stavropoulos, and G. Chryssolouris, "Additive manufacturing methods and modelling approaches: a critical review," *Int. J. Adv. Manuf. Technol.*, vol. 83, no. 1, pp. 389–405, 2016.
- [16] N. Volpato, J. Kretschmer, J. Foggianto, et al., "An investigation on the injection moulding of polymeric parts using rapid tooling inserts," *Journal of Manufacturing Processes*, vol. 20, pp. 463–469, 2015.
- [17] C. M. Cheah, C. K. Chua, and C. W. Lee, "Rapid prototyping and tooling techniques: a review of applications for rapid injection moulding," *Int. J. Adv. Manuf. Technol.*, vol. 25, pp. 308–320, 2005.
- [18] N. A. Meisel and C. B. Williams, "An investigation of key design decisions for AM tooling," in *Proc. 26th Solid Freeform Fabrication Symp.*, 2015, pp. 1590–1603.
- [19] N. Mohan, P. Senthil, S. Vinodh, and N. Jayanth, "A review on FDM process

- optimisation and its applications,” *Rapid Prototyping Journal*, vol. 23, no. 1, pp. 81–91, 2017.
- [20] L. Esposito, S. Testa, and D. Barletta, “Thermal behaviour of polymeric materials under moulding conditions,” *Polymers*, vol. 12, no. 5, p. 1120, 2020.
- [21] I. Sas et al., “Nickel electroplating on polymer surfaces for improved mechanical and thermal properties,” *Surface & Coatings Technology*, vol. 235, pp. 574–580, 2013.
- [22] Y. Zhou, K. Yu, and Z. Li, “Effects of metal reinforcement on polymer tooling,” *Materials & Design*, vol. 142, pp. 54–63, 2018.
- [23] Y. Tian et al., “Heat dissipation enhancement using metal-coated polymer tools,” *Journal of Materials Processing Technology*, vol. 266, pp. 92–101, 2019.
- [24] H. Kim, S. Park, and K. Lee, “Feasibility of rapid tooling using polymer-metal composite moulds,” *Manufacturing Letters*, vol. 29, pp. 32–37, 2021.
- [25] C. C. Kuo et al., “Influence of cooling absence on injection moulding using polymer-based mould inserts,” *Polymer Engineering & Science*, vol. 59, no. 12, pp. 2431–2440, 2019.