MARI

MULTIDISCIPLINARY APPLIED RESEARCH AND INNOVATION
e-ISSN: 2773-4773

Vol. 7 No. 3 (2026) p. 253-262
https://publisher.uthm.edu.my/periodicals/index.php/mari

Design, Fabrication and Thermal-Flow Validation of a Mini Injection Moulding Machine for Engineering Education (Phase 1)

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DOI: https://doi.org/10.30880/mari.2026.07.03.032

Article Info

Received: 01 September 2026
Accepted: 15 October 2026
Available online: 01 December 2026

Keywords

Differential Scanning Calorimetry (DSC), engineering education, free-extrusion, hands-on learning, mini-injection moulding, Polyoxymethylene (POM)

Abstract

Traditional industrial injection moulding machines are often too costly and complex for educational settings, limiting hands-on learning in polymer engineering. This study aims to design, fabricate and systematically validate the thermal and extrusion capabilities of a compact, portable and affordable mini-injection moulding machine tailored for engineering education. In this initial Phase 1 of development, the machine's operational performance was evaluated using Polyoxymethylene (POM) pellet material to verify the heating and gravity-fed flow mechanisms. The characterization involved Differential Scanning Calorimetry (DSC) with a 5 mg to 25 mg sample to map the polymer's thermal processing window, mechanical force testing of the manual lever and a nozzle free-extrusion verification run acting as a critical precursor step prior to mould integration. DSC thermal analysis determined the peak melting point of POM at 198.25 °C , providing the scientific basis for temperature setting. Mechanical evaluation demonstrated that the manual injection lever requires a minimal force of 30 N to 40 N (averaging 33.7 N) to operate, ensuring high safety and ease of use for students. Operational verification proved that POM successfully melted and extruded through the nozzle at a temperature range of 180 °C to 190 °C, yielding a highly continuous, thermally homogeneous extrudate with zero thermal degradation or nozzle clogging. In conclusion, the machine successfully achieved its Phase 1 thermal-flow proof-of-concept milestone, establishing a safe, energy-efficient and cost-effective educational platform that bridges the gap between theoretical polymer science and practical manufacturing applications, while laying a functional baseline for subsequent high-pressure mould-cavity integration. This developed system represents a responsible approach to small-scale plastic manufacturing, emphasizing environmental sustainability and reducing material waste.

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1. Introduction

Injection moulding is a cornerstone of the global plastics industry, accounting for approximately 32% of all plastics consumed worldwide, following extrusion at 36% [1]. This process is essential for modern industrial organizations, enabling the efficient, high-volume and cost-effective production of complex polymer parts. Common examples of injection-moulded products, such as plastic bottles and Lego bricks, are illustrated in Fig. 1(a) and Fig. 1(b), highlighting the integral role of this manufacturing technique in everyday consumer goods.



(a) **(b)**

Fig. 1 *Product of polymer: (a) plastic bottles; (b) lego*

The evolution of plastic injection moulding spans over a century, providing competitive, low-cost alternatives during material shortages. A pivotal moment occurred in 1946 when James Watson Hendry invented the extruding screw injection machine, which revolutionized the industry by offering enhanced control over the production process and significantly improving part quality [2]. Hendry also introduced gas-assisted injection moulding, enabling the production of intricate hollow parts [3]. By the 1970s, plastic production surpassed steel in market share and the introduction of lightweight aluminum moulds in the 1990s offered a faster and more economical alternative to traditional steel tooling [4].

Despite its global importance, significant challenges exist in engineering education. The practical intricacies of polymer science and manufacturing are often hindered by the limitations of industrial equipment. Large-scale injection moulding machines present challenges for academic institutions due to their high capital costs, extensive space requirements and operational complexity [5]. As a result, students frequently miss valuable hands-on learning experiences, creating a gap between theoretical concepts and real-world applications. There is a clear opportunity to design compact, safe and affordable tabletop systems that democratize access to practical manufacturing training.

In Malaysia, the demand for energy-efficient injection moulding systems is growing rapidly, driven by urbanization, retail expansion and packaged goods consumption. However, the local market is predominantly supplied with large-scale industrial machines, such as those from Shuang Sheng Industry. These high manufacturing and acquisition costs, combined with extreme space and infrastructure demands, prevent local educational institutions and vocational schools from adopting such equipment in their laboratories.

While desktop-scale 3D printers have become highly accessible in classrooms, a severe research and development gap remains for affordable, portable and laboratory-safe injection moulding equipment. Existing industrial-grade solutions are too costly and lack portability, making them unfeasible for educational settings with limited budgets. To address this gap, this project aims to develop a small, portable and affordable injection moulding machine suitable for educational use. Emphasizing materials with melting points below 300 °C, the system is optimized for Polyoxymethylene (POM). Specifically, the scope of this initial phase focuses on the fabrication and validation of the heating, mechanical actuation and free-extrusion flow systems. The evaluation aims to verify whether raw POM pellets can be uniformly melted and smoothly extruded through the nozzle under manual lever force. This baseline thermal-flow validation serves as a critical proof-of-concept step, establishing safe operational parameters before proceeding to high-pressure mould-cavity filling in subsequent phases.

2. Available Injection Moulding Technology and Systems

Injection moulding is a widely used manufacturing method where granulated thermoplastic material is heated in a cylinder and then forced through a nozzle into a cooling die to shape the plastic as it solidifies. Although it seems straightforward, it wasn't widely used until the introduction of heat-stable cellulose acetate in 1933, which made the process more effective. The history of injection moulding began with the "packing machine" patented by the Hyatt brothers in 1872 [6]. In 1946, a screw injection machine was introduced, improving the process. Modern machines have two main parts: an injection unit with a heated barrel and a clamping unit for the mould [7]. In 1903, scientists Arthur Eichengrün and Theodore Becke improved the moulding machine and developed soluble cellulose acetate for easier injection moulding. The 1930s saw significant advancements in thermoplastic materials and World War II increased the demand for affordable plastics. James Watson Hendry's invention of the

extrusion screw injection machine in 1946 allowed for high-quality plastic production at lower costs [8]. Injection moulding is versatile, allowing for complex shapes and efficient production, while automation improves consistency and quality. However, it has drawbacks, such as high energy use and potential issues with heavy parts and material processing. Despite these challenges, injection moulding remains a popular choice due to its efficiency, flexibility and quality.

Industrial manufacturing in Malaysia utilizes high-capacity hydraulic, electric and hybrid injection moulding systems to meet mass production demands. While multiple international and local distributors supply these technologies, units from manufacturers like Shuang Sheng Industry serve as representative examples of the standard machinery available in the market as shown in Fig. 2.



(a) **(b)** **(c)**

Fig. 2 *Three main types of machines in the Malaysia market: (a) 52T Hydraulic Injection Moulding Machine SSF520-S [9]; (b) 60T Full Electric Injection Moulding Machine [10]; (c) SH100 Hybrid Injection Moulding Machine [11]*

Table 1 *The specification of three main types of machines available in Malaysia*

		System and Machine		
		Hydraulic	Electric	Hybrid
Machine Unit	Specification	52T Hydraulic Injection Moulding Machine SSF520-S	60T Full Electric Injection Moulding Machine	SH100 Hybrid Injection Moulding Machine
Clamping Unit	Clamp force	520 kN	600 kN	1000 kN
	Max mould thickness	340 mm	400 mm	400 mm
	Min mould thickness	100 mm	160 mm	150 mm
	Ejector stroke	70 mm	70 mm	100 mm
	Ejector number	1	5	5
	Diameter of mould hole	100 mm	100 mm	100 mm
Injection Unit	Screw diameter	25, 28, 32	18, 20	25, 28, 32
	Screw L/D ratio (L/D)	22.6, 20.2, 17.7	24.4, 22	24.6, 22, 19.2
	Shot volume (theoretical) (cm^3)	56, 70, 92	20.3, 25.1	54, 68, 88.5
	Injection weight (PS) (g)	51, 64, 84	18.5, 22	49, 62, 80.5
	Plasticizing capacity (g/s)/ Injection speed	5.6, 6.9, 8.8	350	300
	Injection rate (cm^3/s)	39, 48, 65	89, 110	147, 183, 240
	Injection pressure (MPa):	265, 211, 162	455, 369	275, 220, 168
	Screw speed (rpm):	200	400	400
	Sphere diameter of nozzle(mm)	-	SR10	SR10
Other	Max pump pressure	16 Mpa	-	16 Mpa
	Pump motor power/Servo motor power	11 kW	-	12 kW
	Heating power	4.7 kW	7.5 kW	8.8 kW
	Machine dimension (L*W*H)	3.3*1.1*1.6 m	4.35*1.3*1.6 m	4.4*1.3*1.65 m
	Machine weight	2.2 tons	3.6 tons	3.8 tons
	Oil tank capacity	115 l	-	-

As detailed in Table 1, these industrial units possess extreme operating specifications. They feature physical footprints exceeding 4 m in length, weights ranging from 2.2 to 3.8 tons, and require high-voltage three-phase power supplies with heater power ratings up to 8.8 kW. Clamping units exert forces between 520 kN and 1000 kN to secure moulds with thicknesses up to 400 mm. While highly efficient for factory settings, these specifications explain why industrial machines are virtually impossible to integrate into standard classroom laboratories. Their high procurement costs, massive space requirements, extreme utility demands and severe high-pressure safety risks create an insurmountable barrier for educational institutions.

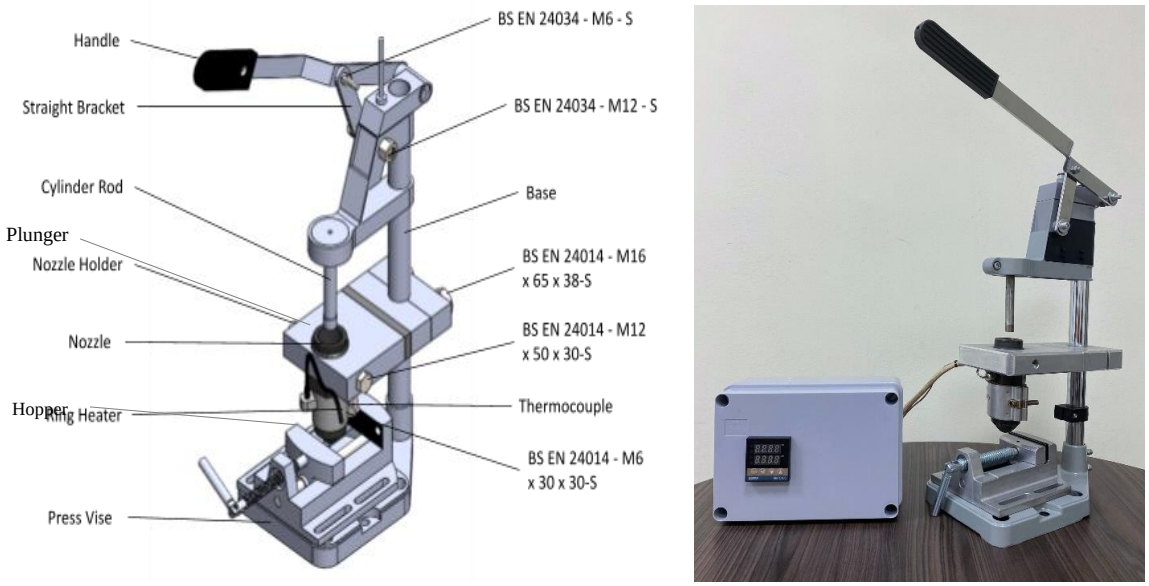
In response to the limitations of industrial machines, several compact, tabletop alternatives have emerged in recent years. Open-Source DIY Systems (Precious Plastic) are globally popularized by the open-source community. These manual injection machines use a vertical plunger and lever mechanism to melt and inject recycled plastic. While highly affordable and portable, they often lack automated closed-loop temperature control and standardized safety shielding, making them less suitable for highly regulated school laboratories. On the other hand, Commercial Tabletop Units (Holipress, Loterios) are professionally manufactured desktop machines designed for small-scale prototyping. They offer precise PID temperature regulation and pneumatic assistance. However, these commercial units remain prohibitively expensive for local educational budgets, with retail prices often exceeding RM 10,000 to RM 15,000, and they frequently require dedicated external pneumatic air lines.

3. Methodology

The evaluation of the mini-injection moulding machine is divided into four distinct phases: machine design and fabrication, thermal characterization of raw materials, mechanical force evaluation and functional verification. Differential scanning calorimetry (DSC) is utilized to analyze the thermal behavior of Polyoxymethylene (POM). Additionally, force testing and injection moulding verification are performed to assess the machine's operational efficiency. The DSC results shed light on the thermal stability and melting characteristics of POM, which are vital for its practical applications. Overall, the force testing and verification processes confirm that the mini injection moulding machine operates effectively, making it suitable for educational purposes.

3.1 Machine Design and Specifications

The mechanical structure of the mini injection moulding machine is designed for compactness and vertical stability as shown in Fig. 3. It features an aluminum drill stand as a sturdy vertical frame, resulting in an overall footprint of approximately 20 cm × 15 cm × 45 cm. This compact size allows multiple units to function simultaneously on a standard classroom bench. The hopper and feed system consists of a steel gravity-feed hopper positioned at the top of the barrel, facilitating the descent of polymer pellets into the heating zone through gravity. This design avoids the complexity of motorized feeding screws. The cylinder barrel and plunger assembly incorporates a lightweight, corrosion-resistant aluminum plunger rod with a diameter of 4.2 cm and a length of 10.1 cm. This configuration optimizes heat transfer while providing a shot capacity of around 15 g to 20 g, adequate for small student specimens. The function of the plunger rod is to push the molten plastic into the mould cavity during the injection process. For clamping, a manual alloy steel press vice is affixed to the base to secure the horizontal split moulds during the cooling process, effectively preventing flashing. This approach eliminates the need for high-pressure hydraulic clamp cylinders.



(a) (b)

Fig. 3 *Mini injection moulding machine: (a) component of mini injection moulding; (b) mini injection moulding machine that has been fabricated*

The polymer pellets then travel down into a heated nozzle, where they are melted by high temperatures generated by a stainless steel ring heater. The heater features an outer diameter of 2 cm and an inner diameter of 1.7 cm, ensuring that the plastic pellets melt uniformly and consistently. For thermal management, a stainless steel ring heater rated at 150 W encircles the nozzle base. The stainless steel material provides strength, corrosion resistance and high-temperature durability. A K-type thermocouple supplies real-time temperature data to a digital PID controller. To address heat conduction concerns, the aluminum holder nozzle acts as a thermal block, dissipating heat before it reaches the main vertical shaft, thus keeping the machine base cool and safe. The temperature is precisely controlled by thermocouples that measure and monitor the temperature of key components such as the barrel, nozzle and mould. These thermocouples transmit data to a temperature controller to maintain the correct temperature range, ensuring consistent melt quality.

The temperature is precisely controlled by thermocouples that measure and monitor the temperature of key components such as the barrel, nozzle and mould. These thermocouples transmit data to a temperature controller to maintain the correct temperature range, ensuring consistent melt quality. Once the plastic is molten, a lever injects it downward into the mould cavity. The injection pressure, applied by the lever, assists in filling the mould, especially for simpler shapes. A cylinder rod, made from aluminum, plays a crucial role in this stage by pushing the melted material into the mould cavity. The aluminum material benefits from lightweight properties, exceptional thermal conductivity and corrosion resistance, facilitating the precise delivery of molten material.

During the injection phase, the two halves of the mould are clamped shut under high pressure by the press vice, also known as the clamping unit. Made from alloy steel, the press vice ensures that the mould halves remain securely sealed under the intense pressure of the injected molten plastic, preventing flash and maintaining the integrity of the final part. The molten plastic undergoes a natural cooling process within the mould cavity until it solidifies. Throughout this cooling phase, the clamping unit maintains its grip to ensure the plastic retains its intended shape. Once the plastic part has sufficiently solidified, the clamping unit releases its pressure, allowing the mould cavity to open horizontally. This facilitates efficient part removal and minimizes the risk of damage to both the part and the mould itself.

The fabricated mini injection moulding machine underwent thorough evaluation. To enhance clarity and avoid redundancy, schematic designs are referenced solely for SolidWorks assembly, while this section emphasizes the operational assessment of the physical prototype. A direct operational comparison with industrial-grade machines, as detailed in Table 1, was conducted to ascertain the performance of this benchtop unit relative to commercial systems. In terms of scale and accessibility, industrial machines require significant installation space and weigh between 2.2 and 3.8 tons, posing challenges for educational use. In contrast, the developed prototype is lightweight and compact, making it easy for students to store and transport.

Regarding pressure and clamping mechanisms, industrial systems typically employ high-pressure hydraulic clamps (ranging from 520 kN to 1000 kN) to prevent flashing. The developed machine effectively substitutes these with a manual alloy steel press vice, which, although not intended for large commercial parts, provides sufficient clamping force to eliminate flashing on small-scale student test specimens. This indicates that the downsizing process retains essential functional mechanics. The holder nozzle is a critical component, measuring 1.66 cm in length, 1.01 cm in width and 2.52 cm in thickness. Its primary role is to secure the nozzle during the injection process, providing stability and support. Constructed from aluminum, it offers lightweight properties, excellent thermal conductivity and resistance to corrosion.

Despite its suitability for educational environments, the machine operates within specific constraints. The temperature limit restricts processing to materials with melting points below 300°C. It is primarily optimized for POM and waxes and cannot handle high-temperature engineering plastics like PEEK or PTFE. Furthermore, the manual clamp force limits part fabrication to flat, low-complexity shapes using simple split moulds. By following these steps, the mini injection moulding machine efficiently transforms plastic pellets into high-quality finished parts, ensuring precision and reliability throughout the process.

3.2 Operational Process

The operational process begins with the melting and injection of material. Polymer pellets are gravity-fed from a hopper located at the top as shown in Fig. 4(a), ensuring optimal part formation during subsequent stages. The vertical orientation of the mould cavity allows gravity, along with the pressure from a lever, to assist in filling the mould with molten plastic, particularly for simpler shapes. Fig. 4(b) shows the pellets are directed into a heated nozzle, where they melt due to high temperatures generated by a surrounding ring heater, which is regulated by a controller. Thermocouples maintain precise temperature control, transforming the pellets into a uniform molten state.

Once melted, a lever injects the material downward into the mould cavity, where a plunger pushes the molten plastic to form the desired shape as illustrated in Fig. 4(c). The material cools naturally within the mould cavity

until solidification occurs. During this phase, the two halves of the mould are clamped shut under pressure, ensuring the molten plastic retains its shape as it cools. The final step involves opening the mould to eject the solidified part, allowing for efficient removal while minimizing damage to both the part and the mould, as depicted in Fig. 4(d).

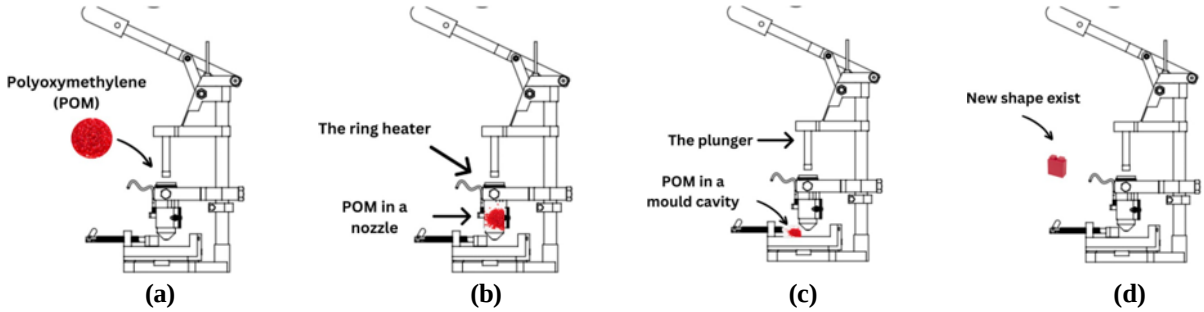


Fig. 4 *The process of using injection moulding machine*

3.3 Evaluation of Mini Injection Moulding

This project encompasses several key experiments to ensure the functionality and effectiveness of the mini injection moulding machine designed for educational use. The force testing experiment measures the extension of a spring under various weights to determine the force constant. Differential Scanning Calorimetry (DSC) is employed to analyze the thermal properties of materials by measuring heat flow during phase transitions. Finally, the injection mould and machine verification experiment assesses the machine's reliability by moulding parts and checking for defects, adjusting parameters as necessary to optimize performance.

3.3.1 Selection of Sample Testing

POM was selected as the primary testing polymer due to its clear educational and engineering benefits. As a high-performance engineering thermoplastic, POM is extensively used in the automotive and mechanical sectors, known for its high stiffness, low friction and excellent dimensional stability, which directly relates to students' professional training. From a processing safety and recyclability standpoint, POM provides a stable processing window and is fully recyclable, unlike PVC, which can emit hazardous gases when overheated. This characteristic supports circular economy principles in the lab, allowing students to regrind and reuse failed moulded specimens. Additionally, its moderate melting point of approximately 198 °C enables efficient melting with low-wattage heaters, aligning well with the machine's energy-saving objectives.

3.3.2 Thermal Characterization via Differential Scanning Calorimetry

DSC is employed to accurately determine the melting point of POM by measuring the heat flow during phase changes using DSC-60 Plus Differential Scanning Calorimeter Shimadzu set with TA-60WS Thermal Analyzer Shimadzu. POM pellets were ground into a fine powder and a sample size of 5 mg to 25 mg was analyzed using DSC. The heating program ramped from 30 °C to 250 °C at a constant heating rate of 10 °C/min increment. The heat flow difference between the sample and reference pan was continuously monitored to identify key thermal transitions.

A precise sample mass of POM encapsulated in a standard aluminum DSC pan, paired with an empty reference pan. Prior to the analysis, the DSC cell was purged with inert nitrogen gas to eliminate the risk of thermal oxidation. This setup allowed for continuous monitoring of heat flow, resulting in a thermogram that delineates the onset, peak melting, and endset temperatures of the polymer. This information is crucial for defining the thermal operational envelope before any moulding activities take place.

3.3.3 Mechanical Actuation Force Testing

The mechanical evaluation centered on the lever actuation of the mini-injection molding machine, focusing on the ergonomics and manual effort necessary for safe operation by students. An Imada DST-110A Digital Force Gauge, capable of measuring up to 110 lb (50 kg) or 500 N, was physically attached to the tip of the manual injection handle to accurately gauge the resistance and peak vertical load required to complete the injection cycle. The lever was pulled downward in a continuous, steady stroke to simulate the manual injection process, with the force gauge recording the corresponding load in newtons (N).

To ensure statistical reliability and minimize human error, the actuation test was repeated five consecutive times, and the average maximum operating force was calculated. Additionally, systematic measurements of force and spring extension were conducted to establish suitable parameters for the force testing experiment. This

involved measuring the initial length of a suspended spring and sequentially adding known weights until equilibrium was achieved, followed by measuring the new length. This process was repeated with various forces to compile a comprehensive data set, meticulously recording the applied force and corresponding spring extensions. By plotting these values, the relationship between force and extension was analyzed, enabling the determination of the spring constant and providing valuable insights into the mechanical properties of the spring.

3.3.4 Nozzle Extrusion and Flow Verification

Instead of conducting high pressure mould cavity injection, this study employed a free-extrusion verification test at the nozzle interface to validate the mini-injection molding machine's capability for processing POM. This procedure is crucial for calibrating the heating zones and assessing the polymer's flow behavior prior to integrating tooling. Raw POM pellets were gravity-fed from the hopper into a heated barrel cylinder, where the temperature of the stainless steel ring heater was maintained between 180 °C and 190 °C. This temperature was monitored using K-type thermocouples linked to a digital PID controller. Once the target temperature stabilized, a steady manual force of 30 N to 40 N was applied to the lever, pushing down the aluminum cylinder rod to compress and drive the molten polymer through the nozzle.

Visual Validation Check: The extruded polymer was allowed to flow freely into the air, and the resulting physical extrudate was inspected for three key criteria: (i) Flow continuity: Ensuring a consistent, uninterrupted stream of molten polymer. (ii) Thermal homogeneity: Confirming the complete melting of pellets without any solid, unmelted cores, and (iii) Thermal degradation: Checking for signs of burning or overheating, such as yellowing, black spots or smoke. Following the extrusion test, the injection mold and machine verification experiment aimed to assess the mini-injection molding machine's ability to mould POM material effectively. This involved selecting an appropriate mould, ensuring both the mould and machine were clean and operational. The mould was installed, parameters such as temperature and pressure were adjusted according to POM specifications. A verification run was then conducted, during which the molded parts were inspected for defects. This iterative process continued until satisfactory results were obtained, confirming the machine's performance and its capacity to produce high-quality POM parts reliably.

4. Evaluation of POM Thermal Properties Using DSC

The thermal behavior of the Polyoxymethylene (POM) pellet material was analyzed using Differential Scanning Calorimetry (DSC) to establish the correct polymer processing window. The thermogram shows a highly stable baseline until it reaches the melting transition zone as shown in Fig. 5. At this point, the curve exhibits a single, sharp endothermic peak. The thermal transition is characterized by an onset temperature of 195.62 °C, a peak melting temperature of 198.25 °C, and an endset temperature of 201.50 °C. The glass transition temperature is observed at approximately 156.14 °C. The sharp and narrow profile of the endothermic peak indicates that POM is a highly crystalline thermoplastic. This narrow melting range has critical processing implications: (i) Rapid Phase Transition: the polymer transitions very rapidly from a solid crystalline structure to a low-viscosity liquid state within a narrow span of approximately 6°C (between onset and endset). (ii) Temperature Control Rigor: because of this rapid crystallization, the operating temperature must be strictly controlled using the closed-loop PID controller. If the temperature drops slightly below 195 °C, the polymer will solidify instantly, clogging the nozzle. Conversely, heating POM significantly above its endset temperature increases the risk of thermal degradation. Thus, the DSC results scientifically justify setting the machine's operational temperature range to 180 °C to 190 °C (for early softening) and up to 200 °C for smooth injection.

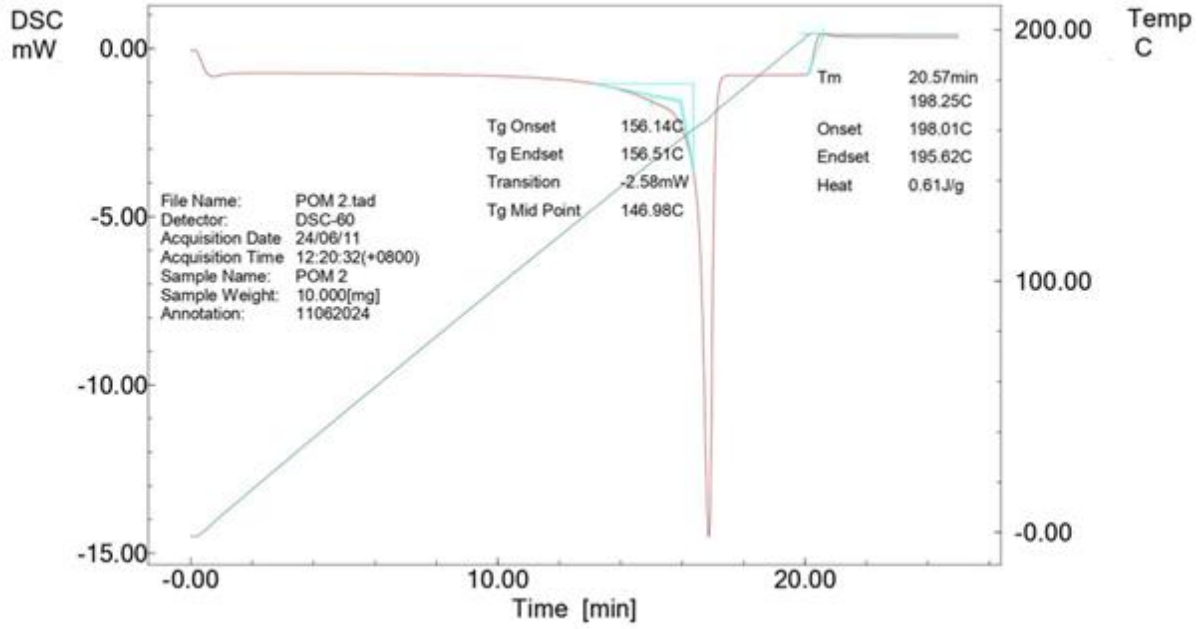


Fig. 5 *DSC curve for POM material*

5. Evaluation of Manual Actuation Force Testing

The primary objective of the force testing was to evaluate the ergonomic safety of the manual lever design and ensure that the physical force required to actuate the injection cycle is suitable for undergraduate students of varying physical capabilities. The experimental results demonstrated that the manual handle requires a peak actuation force of 30 N to 40 N, with a highly repeatable average of 33.7 N. This yields significant Practical and Educational Contributions. First, Ergonomic Suitability: a force of 33.7 N is equivalent to lifting approximately 3.4 kg. This ultra-low force requirement proves that the mechanical advantage provided by the lever arm is highly efficient, allowing any student to safely execute the injection stroke without physical strain or injury. Second, Elimination of Auxiliary Infrastructure: by keeping the operating force below 40 N, the machine operates completely independent of heavy, noisy, and expensive pneumatic compressors or hydraulic pumps. This independent mechanism maximizes classroom safety, keeps fabrication costs low (RM 213.09), and ensures the machine remains highly portable between different classrooms.

6. Nozzle Extrusion Validation and Flow Homogeneity

The operational capability of the fabricated machine was successfully verified through free-extrusion tests using POM pellets. The verification runs demonstrated that the mini-machine operates effectively, with the polymer melting and extruding smoothly through the nozzle at a temperature range of 180 °C to 190 °C under a manual lever force of 30 N to 40 N. Visual inspection of the extruded POM confirmed a highly continuous and uniform cylindrical profile as shown in Fig. 6. The extrudate exhibited zero unmelted pellet particles, indicating that the heat transfer from the 150 W stainless steel ring heater through the aluminum cylinder barrel is highly efficient and even. Furthermore, the extruded polymer maintained its natural white color with no signs of thermal degradation, such as yellowing or carbonized black spots, validating that the 180 °C to 190 °C processing window is thermally safe. Prioritizing a free-extrusion flow test is a standard engineering approach that allows the operator to: (i) Verify the exact temperature settings and heater power stability under zero mould back pressure, (ii) Ensure that the manually actuated lever (average force of 33.7 N) can overcome the shear viscosity of molten POM safely, and (iii) Mitigate safety risks in a student laboratory environment, ensuring the machine frame and base remain thermally isolated and structurally stable under heat before high-pressure moulding cycles are introduced.

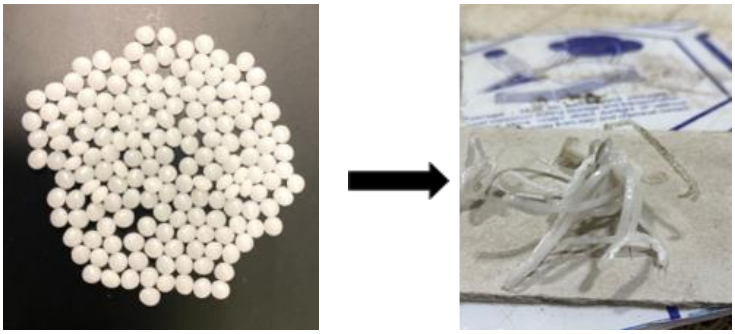


Fig. 6 *Extrusion outcome of POM material*

7. Conclusion and Recommendation

The portable, lightweight, and affordable mini-injection moulding machine was successfully designed, fabricated, and operated. Operational verification runs confirmed the machine's efficacy, demonstrating that POM successfully melted and extruded through the nozzle at temperatures between 180 °C and 190 °C under a manual lever actuation force of 30 N to 40 N (averaging 33.7 N). Furthermore, DSC thermal analysis determined the melting point of POM at 198.25 °C, with a glass transition at approximately 156.14°C, verifying the polymer's thermal stability up to its melting point. A key technical challenge encountered during operation was managing thermal distribution to prevent material degradation while ensuring that the high operating temperatures (180 °C to 190 °C) did not structurally damage the machine's base cylinder, which was successfully resolved through the thermal isolation provided by an engineered aluminum holder nozzle. This project significantly contributes to engineering and STEM education by offering a safe, hands-on pedagogical tool that bridges the gap between theoretical polymer science and practical manufacturing. To enhance the machine's utility and expand its academic scope, the following future research and development pathways are recommended: (i) Enhance thermal precision: refine the heating assembly and PID controller calibration to ensure highly precise temperature stability when processing various polymer materials with melting points below 300 °C. (ii) Expand material compatibility: investigate the compatibility of the machine with biodegradable and environmentally friendly plastics to promote green polymer technology and circular manufacturing principles within the educational curriculum.

Acknowledgement

The authors would like to thank the Centre for Diploma Studies, Universiti Tun Hussein Onn Malaysia for its financial support and facilitation in this project.

Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Nur Alya Muhamad Rahi, Nur Atikah Mohd Asnizam, Muhammad Haqimee Mohd Arif, Hafsa Mohammad Noor;* ***data collection:*** *Nur Alya Muhamad Rahi, Nur Atikah Mohd Asnizam, Muhammad Haqimee Mohd Arif;* ***analysis and interpretation of results:*** *Nur Alya Muhamad Rahi, Nur Atikah Mohd Asnizam, Muhammad Haqimee Mohd Arif, Hafsa Mohammad Noor;* ***draft manuscript preparation:*** *Nur Alya Muhamad Rahi, Nur Atikah Mohd Asnizam, Muhammad Haqimee Mohd Arif, Hafsa Mohammad Noor. All authors reviewed the results and approved the final version of the manuscript.*

References

[1] Tekwell Machinery, "*Standard test process of injection mold*," Oct. 13, 2022. Accessed: Jul. 3, 2024. [Online]. Available: https://tekwellmachinery.com/standard-test-process-of-injection-mold/
[2] Daya Machinery, "*Injection molding machine nozzle*," Aug. 29, 2019. Accessed: Jul. 1, 2024. [Online]. Available: https://www.dayamachinery.com/injection-molding-machine-nozzle/
[3] D. V. Rosato and M. G. Rosato, *Injection Molding Handbook*. New York, NY, USA: Springer, 2015.
[4] A. Doyle, "Environmentally friendly alternative to polystyrene foam," *The Chemical Engineer*, Jul. 17, 2019. Accessed: Jul. 15, 2026. [Online]. Available: https://www.thechemicalengineer.com/news/environmentally-friendly-alternative-to-polystyrene-foam/

[5] N. C. Fei, N. M. Mehat, and S. Kamaruddin, "*Practical applications of Taguchi method for optimization of processing parameters for plastic injection moulding: A retrospective review*," ISRN Industrial Engineering, vol. 2013, Art. no. 462174, 2013, doi: 10.1155/2013/462174.
[6] Rubin, *Injection Moulding: Theory and Practice*. New York, NY, USA: Wiley, 1972.
[7] R. Zheng, X.-J. Fan, and R. I. Tanner, *Injection Moulding: Integration of Theory and Modeling Methods*. Berlin, Germany: Springer-Verlag, 2011.
[8] Xometry, "*Plastic injection moulding history*," Apr. 29, 2022. Accessed: Jun. 4, 2026. [Online]. Available: https://www.xometry.com/resources/injection-moulding/plastic-injection-moulding-history/
[9] SS Machinery, "*52TON hydraulic servo plastic injection moulding machine*," 2026. Accessed: Jun. 4, 2026. [Online]. Available: https://www.ssmachinery.com/ssf520-2/
[10] SS Machinery, "*Full electric injection molding machine*," 2026. Accessed: Jun. 4, 2026. [Online]. Available: https://www.ssmachinery.com/60t-full-electric-injection-moulding-machine/
[11] SS Machinery, "*(Injection weight: 49–80.5 g) hybrid injection molding machine*," 2026. Accessed: Jun. 4, 2026. [Online]. Available: https://www.ssmachinery.com/sh100-hybrid-injection-molding-machine/