engineering proceedings

MDPI

Proceeding Paper

Design of Modular Mold for Injection Molding of Small-Sized Nonmetal Parts †

Anna-Maria Lazarova [1,*], Stiliyan Nikolov [1,2] and Reneta Dimitrova [1,3]

[1] Department of Automation of Discrete Production Engineering, Technical University of Sofia, 1000 Sofia, Bulgaria; st_nikolov2@tu-sofia.bg (S.N.); rkd@tu-sofia.bg (R.D.)
[2] National Centre of Excellence, "Mechatronics and Clean Technologies", 1000 Sofia, Bulgaria
[3] Competence Center for Mechatronics and Clean Technologies "Mechatronics, Innovation, Robotics, Automation and Clean Technologies"—MIRACle, 1000 Sofia, Bulgaria
* Correspondence: anna-maria.lazarova@tu-sofia.bg; Tel.: +359-876-025-262
† Presented at the International Conference on Electronics, Engineering Physics and Earth Science (EEPES2026), Bandirma, Turkey, 24–27 June 2026.

Abstract

The article analyzes the design of molds for the production of nonmetallic parts by injection molding. Based on the analysis on an existing mold, a mold with a modular design was developed in environment of the SolidWorks Version 2022 CAD system. The developed design of the matrix serves for the production of small-sized nonmetallic parts, with the possibility of readjustment when changing the parts being produced. The main steps necessary for readjusting the developed mold when changing the manufactured parts are defined. The proposed modular mold design was manufactured and tested during injection molding of two parts, "Handle" and "Fork". The results obtained during the testing show the operability of the proposed design. The proposed modular mold design reduces the time and costs required to transition production from one part to another.

Keywords: mold; small-sized nonmetal parts; injection molding; modular design

1. Introduction

Nonmetal parts can nowadays be found in the construction of most modern products. According to [1], nonmetal parts manufactured by injection molding, depending on the overall dimensions, mass, size, and the clamping force of the machine, can be divided into:

- Small-sized—characterized by a mass below 0.05 [kg], dimensions of 1 ÷ 25 [mm], and a machine clamping force of up to 50 [t];
- Medium-sized—characterized by a mass of 0.05 ÷ 1 [kg], dimensions of 25 ÷ 300 [mm], and a machine clamping force of 50 ÷ 200 [t];
- Standard—characterized by a mass of 1 ÷ 11.5 [kg], dimensions of 300 ÷ 900 [mm], and a machine clamping force of 200 ÷ 800 [t];
- Large-sized—characterized by a mass above 11.5 [kg], dimensions above 900 [mm], and a machine clamping force above 800 [t].

Injection molding, also known as injection forming, is one of the most commonly used technological processes for the production of nonmetal products, distinguished by high accuracy and good repeatability of the obtained parts [2]. It ensures efficiency of the production process and enables mass production of nonmetal parts with high quality and low costs, high dimensional accuracy, excellent mechanical properties, and a minimal scrap rate [3].

Check for updates

Academic Editors: Teodor Iliev, Ivaylo Stoyanov, Grigor Mihaylov and Selahattin Kosunalp

Published: 3 September 2026

Copyright: © 2026 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license.

Injection-molding equipment is based on the equipment used for casting metal in permanent molds (dies).

The mold is the tool used in injection molding. It is designed and manufactured for each specific part. It consists of two parts that are mounted on the two plates of the molding unit of the injection-molding machine. When the molding unit is opened, the two halves of the mold open [4,5].

The main systems included in the mold construction are:

- Forming system—determines the dimensions and shape of the produced part and allows the mold to be divided into two parts for the removal of the injection-molded part;
- Guiding system—ensures the relative positioning of the two parts of the mold and their movement with respect to each other during the operation of the machine;
- Part ejection system—ensures the ejection of the part from the forming cavity when the mold is opened;
- Material feeding system—ensures the supply of the molten material to the forming cavity of the mold;
- Gas venting system—ensures the removal of gases from the forming cavity of the mold during its filling with molten material;
- Cooling system—ensures the removal of heat from the forming cavity of the mold in order to reduce the time required for material solidification.

Depending on the size of the produced parts and the machine used for this purpose, several parts can be produced simultaneously with one mold in a single operating cycle.

For the production of parts with different designs and dimensions, it is necessary to use a mold specifically developed for the respective part.

The cost of designing and manufacturing the mold is one of the main factors determining the cost price of the parts produced with it [6,7].

The desire of manufacturers to respond as quickly as possible to market changes in order to maintain their market share requires a rapid transition from the production of one product to another. In this regard, the development of new mold designs for the production of small nonmetallic parts, with the ability to quickly adjust and minimal cost, is a current problem.

The aim of the present work is to design a modular, reconfigurable mold that, after minimal modifications in its construction, can be used for the production of various small-sized nonmetal parts.

2. Materials and Methods

2.1. Analysis of the Design of Molds for the Production of Nonmetal Parts

The construction of a mold for the production of nonmetal parts by injection molding includes a set of plates performing different functions, guiding elements providing the necessary movements, pins, elastic elements ensuring the movement of the movable components, and fastening elements for connecting the individual components into two separate assemblies [8–11].

The individual systems included in the construction of a mold, discussed above, use different elements from the construction of the individual parts. In this way, a single part serves as a component of several different systems [4].

The most complex in design and containing the largest number of components from the different systems of the mold are the plates forming the molding cavity (forming plates) [12]. For example, in the construction of the forming plates shown in Figure 1, “Fixed forming plate” and “Movable forming plate”, elements from all systems are included.

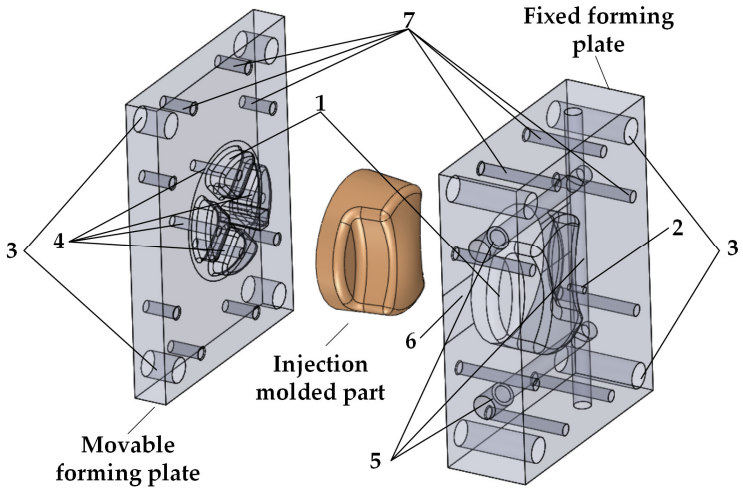


Figure 1. Forming plates: (1) forming surfaces; (2) central hole; (3) peripheral holes; (4) holes; (5) cooling holes; (6) channels; (7) threaded holes.

These elements are as follows:

- Forming surfaces (pos. 1 Figure 1)—part of the forming system, forming the molding cavity that determines the shape and dimensions of the produced parts (in this case, the mold is designed for the production of only one part).
- Central hole (pos. 2 Figure 1) —part of the material feeding system, ensuring the flow of the molten material from the nozzle of the injection cylinder of the machine to the molding cavity. The shape and number of the distribution channels depend on the shape and number of the parts produced simultaneously.
- Peripheral holes (pos. 3 Figure 1)—part of the guiding system.
- Holes (pos. 4 Figure 1)—part of the ejection system, provide access to the part for the ejector pins, which push the part out of the molding cavity when the mold is opened.
- Cooling holes (pos. 5 Figure 1)—part of the cooling system.
- Channels (pos. 6 Figure 1)—part of the gas venting system. A large part of the generated gases and the air trapped in the molding cavity pass through the clearances around the ejector pins. If necessary, additional ventilation channels are made on the parting surface of the mold, with a depth of about 0.03 [mm] and a width of 12 to 25 [mm] [13].
- Threaded holes (pos. 7 Figure 1)—provide the possibility for connecting the individual parts into two separate halves of the mold, mounted to the movable and fixed plates of the machine [14].

The most complex to manufacture and the most expensive are the parts that are part of the forming system and form the molding cavity of the mold.

2.2. Molds for the Production of Small-Sized Nonmetal Parts

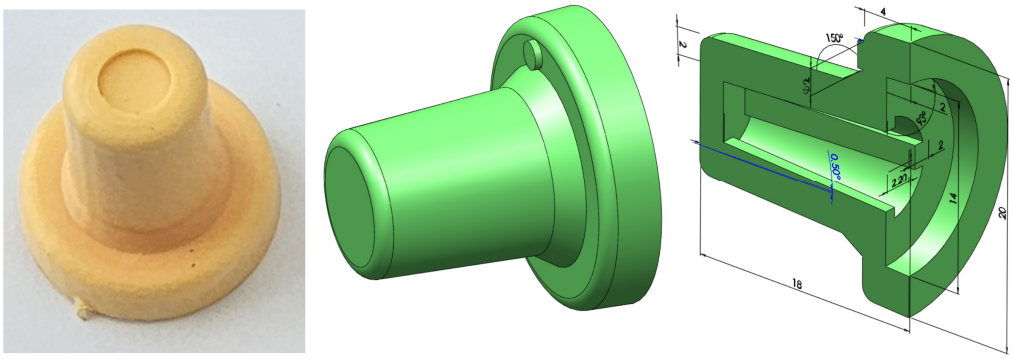
Considering the small mass and dimensions of small-sized nonmetal parts, molds for their production are usually designed for the simultaneous injection molding of several parts. Most often, identical parts are produced simultaneously, which ensures identical conditions for filling the molding cavity, which in this case is symmetrical, and for cooling the obtained molding.

In the construction of molds for the production of small-sized nonmetal parts, the following are often absent:

- Gas venting system—due to the small volume of the mold cavity that must be filled with molten material, the amount of gases is small, and for their removal, the clearances around the ejector pins are sufficient;
- Cooling system—due to the small amount of material to be solidified, the heat dissipation provided by the plates in which the molding cavity is made is sufficient for removing heat from the molding cavity of the mold.

2.3. Molds for the Production of the Part "Handle"

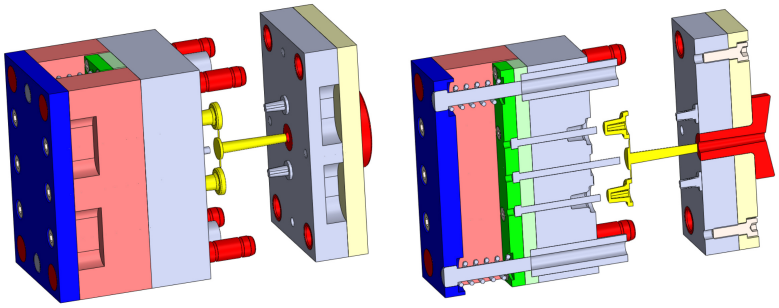
As a base of the designed mold, a mold for injection molding of the part "Handle", with dimensions 18 × ø20 [mm] and mass 0.0018 [kg], shown in Figure 2, will be used.



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

Figure 2. 3D model. Part "Handle": (**a**) real part; (**b**) 3D model.

The overall and mounting dimensions of the mold are in accordance with the working area of the injection molding machine ROBOSHOT α-S15iB by FANUC [15]. The 3D model of the mold, developed using the CAD system SolidWorks Version 2022, is shown in Figure 3. Figure 3a represents the 3D isometric view of the mold for injection molding of the part "Handle". Figure 3b represents the 3D section view of the mold.



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

Figure 3. 3D model of the mold for injection molding of the part "Handle": (**a**) 3D isometric view; (**b**) 3D section view.

The main costs in the manufacturing of the mold are associated with the production of the forming plates like those shown in Figure 1. At the same time, the wear of these plates has a significant impact on the quality of the produced parts.

3. Results

Considering the small and approximately equal dimensions of small-sized nonmetal parts, based on the mold shown in Figure 3, a modular mold has been developed, in which the forming plates (Figure 4) are divided into two parts:

- Main part (pos. 2 Figure 4), in which the elements of the guiding system and part ejection system are reserved;
- Forming part (pos. 1 Figure 4), in which the elements of the forming system and the material feeding system are reserved.

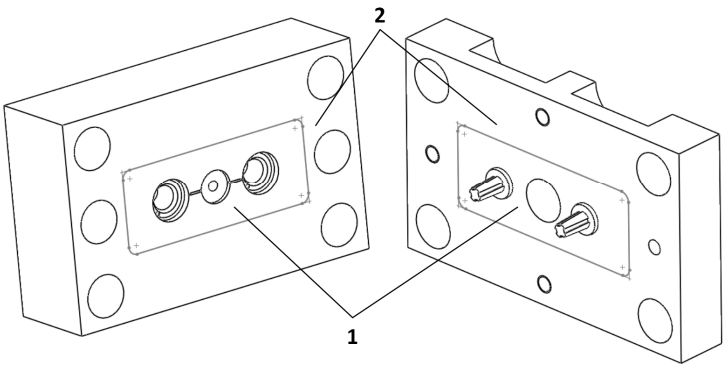


Figure 4. Forming plates: (1) forming part; (2) main part.

The forming part can be removed from the main part and replaced with a new one in case of wear or when injection molding another part.

The result of this separation developed using the CAD system SolidWorks is shown in Figure 5.

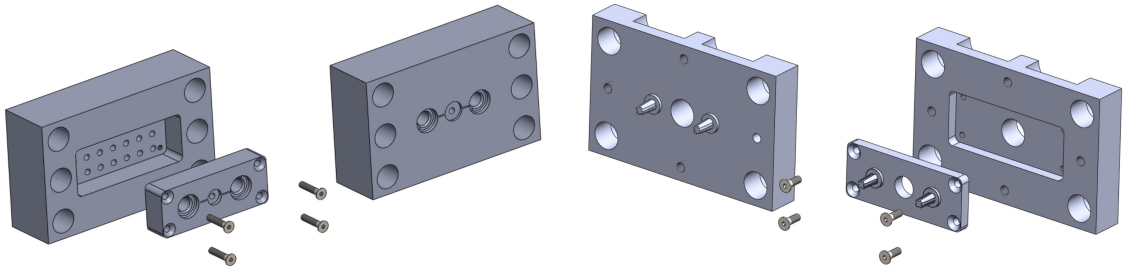


Figure 5. Separation of molding plates: (**a**) "Movable forming plate"; (**b**) "Fixed forming plate".

In order to provide the possibility for reconfiguration of the modular mold, modifications have also been made to the support plates, which allows changing the positions of the ejector pins when the molding cavities are arranged differently.

The 3D model of the developed modular mold is shown in Figure 6. Figure 6a shows the 3D section view of the closed modular mold and Figure 6b shows the 3D section view of the opened modular mold.

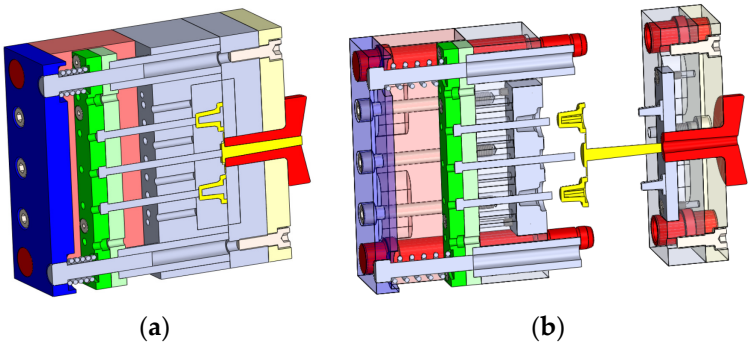
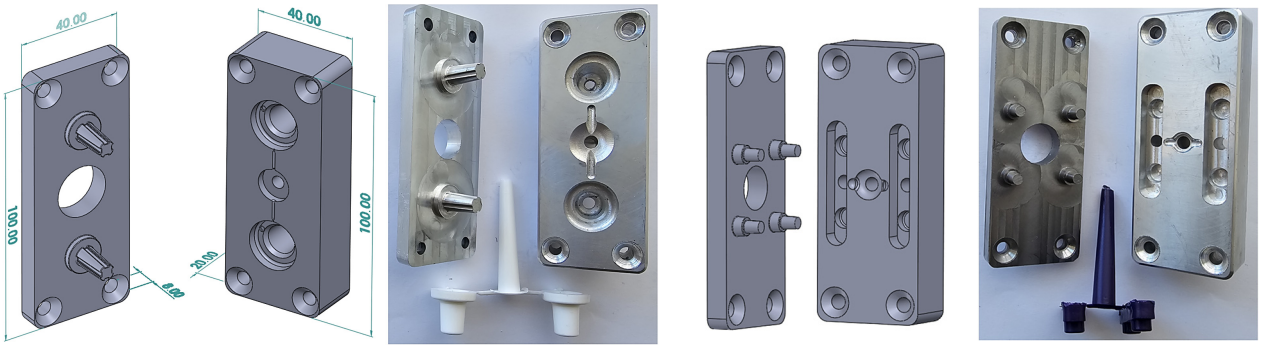


Figure 6. 3D model of the developed modular mold: (**a**) 3D section view of closed modular mold; (**b**) 3D section view of opened modular mold.

https://doi.org/10.3390/engproc2026154036

The proposed modular mold design was manufactured and tested during injection molding of two parts "Handle" and "Fork". The forming parts for the production of the parts "Handle" and "Fork", using the developed modular mold, and the injection-molded parts are shown in Figure 7.



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

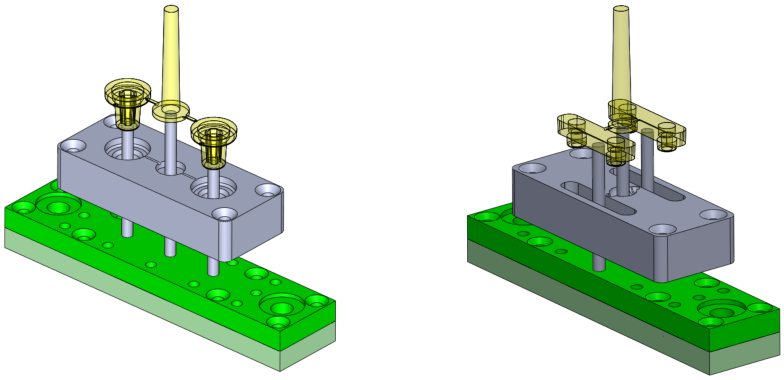
Figure 7. Forming parts for the production of the parts: (**a**) "Handle"; (**b**) "Fork".

4. Discussion

The developed design of the modular mold allows, in case of wear, quick replacement of the forming parts without the need to remove the mold from the injection molding machine.

When changing the injection-molded part, in addition to changing the molding parts, it is necessary to:

- Rearrange the ejector pins Figure 8—the position of the ejector pins depends on the number of parts being manufactured simultaneously and the location of the forming cavities;
- Adjust the length of the ejector pins—it is necessary to make new ejector pins, the length of which depends on the shape of the new part will being made;
- Adjust the stroke of the ejector pins—it is necessary to make new ejector sleeves of appropriate length.



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

Figure 8. Rearrange the ejector pins for the production of the parts: (**a**) "Handle"; (**b**) "Fork".

Performing these activities requires downthrowing the mold from the injection molding machine, disassembling the mold, making ejector pins and ejector sleeves of the appropriate length, assembling the mold with reconfiguring the ejector pins, and uploading the mold in the machine.

https://doi.org/10.3390/engproc2026154036

Considering the dimensions of the forming parts 100 × 40 × 20 [mm] and 100 × 40 × 8 [mm], as shown in Figure 7, with the developed modular mold, parts with dimensions within the limits of 80 × 30 × 20 [mm] can be produced.

The significant reduction in the size of the plates in which the molding cavities are made reduces the volume of scrap in case of errors related to their manufacturing, which is the most labor-intensive process.

For the developed molds, the volume of the blanks for plates in which the forming cavities are made decreases as follows:

- For the part "Handle"—forming part of movable plate from 80,000.0 [mm^3] to 71,637.4 [mm^3], forming part of fixed plate from 96,000.0 [mm^3] to 29,836.0 [mm^3], Main part of movable plate from 720,000.0 [mm^3] to 568,203.5 [mm^3], main part of fixed plate from 400,000.0 [mm^3] to 321,831.5 [mm^3], and total volume reduction from 1,296,000.0 [mm^3] to 304,491.6 [mm^3], by 23.5%;
- For the part "Fork"—forming part of movable plate from 80,000.0 [mm^3] to 71,601.5 [mm^3], forming part of fixed plate from 72,000.0 [mm^3] to 30,108.5 [mm^3], main part of movable plate from 720,000.0 [mm^3] to 563,326.2 [mm^3], main part of fixed plate from 400,000.0 [mm^3] to 321,831.5 [mm^3], and total volume reduction from 1,272,000.0 [mm^3] to 285,132.8 [mm^3], by 22.4%.

For the molds, before modification, the volume of the blanks for plates in which the forming cavities are made decreases as follows:

- For the part "Handle"—movable plate from 720,000.0 [mm^3] to 619,864.1 [mm^3], fixed plate from 656,000.0 [mm^3] to 353,638.9 [mm^3], and total volume reduction from 1,376,000.0 [mm^3] to 402,497.0 [mm^3], by 29.3%;
- For the part "Fork"—movable plate from 720,000.0 [mm^3] to 638,591.4 [mm^3], fixed plate from 750,000.0 [mm^3] to 354,020.0 [mm^3], and total volume reduction from 1,440,000.0 [mm^3] to 447,385.6 [mm^3], by 31.1%.

Since the reduced volume during manufacturing is converted into scrap, based on the data above, it can be said that during the manufacturing of the developed modular mold, the volume of scrap compared to the original mold is reduced as follows:

- For the part "Handle": Original mold—reduced volume 402,497.0 [mm^3], developed modular mold—reduced volume 304,491.6 [mm^3], and reduction of 98,005.4 [mm^3], by 24.3%;
- For the part "Fork": Original mold—reduced volume 447,385.6 [mm^3], developed modular mold—reduced volume 285,132.8 [mm^3], and reduction of 162,252.2 [mm^3], by 36.3%.

The reduction in scrap, received during the manufacturing of the developed modular mold, leads to a reduction in production costs and production time.

If an error is made in the manufacturing of the forming surfaces, which are the most labor-intensive to produce, the entire workpiece turns into scrap. The volume of these parts is many times smaller in the developed modular mold, six, eight and nine times per part for "Handle" and 10 and nine times per part "Fork", for the fixed or movable plates.

When reconfiguring the modular mold for injection molding of a new part, all components are used except: the forming part of movable plate; the forming part of fixed plate; and the ejector pins and ejector sleeves. This significantly reduces the costs and time required to switch from producing one part to another.

5. Conclusions

The design of molds for the production of nonmetal parts by injection molding has been analyzed.

https://doi.org/10.3390/engproc2026154036

Based on the analysis, a modular mold has been developed for the production of small-sized nonmetal parts, with the possibility of readjustment when changing the parts being produced.

The proposed design of a modular mold has been tested during the injection molding of the "Handle" and "Fork" parts.

The results obtained during the testing show the operability of the proposed design.

The proposed modular mold design reduces the time and costs required to transition production from one part to another.

Author Contributions: A.-M.L., S.N. and R.D. were involved in the full process of producing this paper, including conceptualization, methodology, modeling, validation, visualization and preparing the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: Research and Development Sector at the Technical University of Sofia.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are obtained in the article.

Acknowledgments: The authors would like to thank the Research and Development Sector at the Technical University of Sofia. This work was supported by European Regional Development Fund under "Research. Innovation and Digitization for Smart Transformation" program 2021–2027 under the Project BG16RFPR002-1.014-0006 "National Centre of Excellence Mechatronics and Clean Technologies". This work was accomplished by the Center of Competence for Mechatronics and Clean Technologies "Mechatronics, Innovation, Robotics, Automation and Clean Technologies"—MIRACle, with the financial support of contract No. BG16RFPR002-1.014-0019-C01, funded by the European Regional Development Fund (ERDF) through the Program "Research, Innovation and Digitalisation for Smart Transformation" (PRIDST) 2021–2027.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviation

The following abbreviation is used in this manuscript:

CAD Computer-aided design

References

1. Freeform Polymers. How Large Can Injection Molding Parts Be? (Size Limits & Capabilities Guide). 2025. Available online: https://freeformpolymers.com/how-large-can-injection-molding-parts-be-size-limits-capabilities-guide/ (accessed on 16 January 2026).
2. Groover, M.P. *Fundamentals of Modern Manufacturing: Materials, Processes, and Systems*, 5th ed.; John Wiley & Sons: Hoboken, NJ, USA, 2013.
3. Lin, W.-C.; Fan, F.-Y.; Huang, C.-F.; Shen, Y.-K.; Wang, H. Analysis of the Warpage Phenomenon of Micro-Sized Parts with Precision Injection Molding by Experiment, Numerical Simulation, and Grey Theory. *Polymers* **2022**, *14*, 1845. [CrossRef] [PubMed]
4. Schneider, D.; Reichert, V. Modular technological inserts for injection molding machines. *Proc. AIP Conf. Proc.* **2017**, *1914*, 140005. [CrossRef]
5. Li, X.; Liu, F.; Zhang, C.; Gao, R.; Xu, X.; Fu, J.; Zhao, P. The influence of mold design and process parameters on dimensional shrinkage of perfluoro alkoxy alkane injection molding parts. *J. Appl. Polym. Sci.* **2024**, *141*, e55757. [CrossRef]
6. Yamazaki, Y.; Kankawa, Y. Superiority of V-LINE® Injection Molding Machine in Metal Injection Molding for Precise Parts. *J. Jpn. Soc. Powder Powder Metall.* **2025**, *72*, S635–S639. [CrossRef]
7. Matin, I.; Hadzistevic, M.; Hodolic, J.; Vukelic, D.; Lukic, D. A CAD/CAE-integrated injection mold design system for plastic products. *Int. J. Adv. Manuf. Technol.* **2012**, *63*, 595–607. [CrossRef]
8. Deng, K.; Zhao, G.; Wang, J. High-Thermal Conductivity Aluminum Alloy Mold Inserts: Improving Injection Efficiency and Mechanical Properties of ABS Molded Parts. *Polym. Adv. Technol.* **2025**, *36*, e70445. [CrossRef]

9. Raz, K.; Chval, Z.; Hula, F.; Markopoulos, A. Surface Treatment and Analysis of 3D-Printed Plastic Molds for Prototype and Small-Series Injection Molding. *Polymers* **2025**, *17*, 2977. [CrossRef] [PubMed]
10. Shih, C.-J.; Huang, P.-W.; Hwang, S.-J. Correlation Between In-Mold Pressure and Residual Stress in Cyclo-Olefin Copolymer Injection Molding Using Birefringence Analysis. *Polym. Eng. Sci.* **2026**, *66*, 4234–4246. [CrossRef]
11. Li, Y.-H.; Kang, J. Design and Process Analysis of the Injection Mold for Extrusion Valves. *J. Phys. Conf. Ser.* **2025**, *3004*, 012073. [CrossRef]
12. Márquez, J.J.; Rueda, J.; Chaves, M.L. Design and Manufacturing of a Modular Prototype Mold to be employed in Micro Injection Molding Experiments. *AIP Conf. Proc.* **2009**, *1181*, 353–361. [CrossRef]
13. Krantz, J.; Nieduzak, Z.; Licata, J.; O'Meara, S.; Gao, P.; Masato, D. In-mold rheology and automated process control for injection molding of recycled polypropylene. *Polym. Eng. Sci.* **2024**, *64*, 4112–4127. [CrossRef]
14. Zaniboni, G.; Pelaccia, R.; Surace, R.; Orazi, L.; Fassi, I.; Basile, V. Resin molds for improving thermal management in the injection molding process. *Procedia Comput. Sci.* **2026**, *277*, 1548–1557. [CrossRef]
15. FANUC. α-S15iB Mechanical Specifications. Available online: https://www.fanuc.eu/eu-en/product/roboshot/roboshot-a-s15ib (accessed on 1 March 2026).

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.