A multi-step approach for analyzing the number of polymer injection molding gate spots and their position in T-RTM technology

Blagovest Bankov
Department of „Armament and Technology for Design"
National Military University "Vasil Levski"
Shumen, Bulgaria
blagovest.bankov@gmail.com

Todor Todorov
FIT, Laboratory "CAD/CAM/CAE in Industry", Technical University
Sofia, Bulgaria
todorttodorov@tu-sofia.bg

Yavor Sofronov
FIT, Laboratory "CAD/CAM/CAE in Industry", Technical University
Sofia, Bulgaria
ysofronov@tu-sofia.bg

Ivan Ivanov
FIT, Laboratory "CAD/CAM/CAE in Industry", Technical University
Sofia, Bulgaria
ivan.st.ivanov@abv.bg

Abstract. **The purpose of this study is to present a multi-step approach for building a virtual analysis supporting the determination of the number and position of the injection molding gate spots in Resin Transfer Molding (RTM) and the relatively new Thermoplastic Resin Transfer Molding (T-RTM) technologies. The methodology provides an opportunity to determine the behavior of the fluid flow based on the location of the inlets, as well as potential problems and defects.**

Keywords: Injection Molding, Moldex3D, Polymer, T-RTM

I. INTRODUCTION

Composite products are increasingly occupying a larger share of the market, being used in the aviation and automotive industries, the production of various sports facilities, and building elements, with the goal of reducing the overall weight and thereby enhancing various characteristics that directly affect the life cycle of the final product [1], [2], [3], [4], [5].

Strategies for using fewer raw materials and creating less environmental pollution are adopted for the creation of such composite products, which can be more easily processed after they are no longer in use. The relatively new technology "Thermoplastic Resin Transfer Molding" (T-RTM) is used for their creation, combining the advantages of "Resin Transfer Molding" (RTM) technology with those of the thermoplastic matrix (recyclability, workability, plasticity, durability, etc.) and the high-pressure injection from the "High-Pressure Resin Transfer Molding" (HP-RTM) technology [6], [7], [8].

Although RTM technology and its processes are well known to process engineers, there are still various difficulties in creating large parts. With the development of computer technologies and mathematical models, manufacturers have the opportunity to analyze and optimize processes in advance by creating virtual prototypes to be investigated with specialized software products [9], [10], [11], [12], [13], [14], [15], [16], [17], [18], [19], [20], thereby reducing the potential risks of defective products and financial losses.

One of the important steps in creating a quality product through RTM and T-RTM technologies is the initial determination of the number, type, geometry, and position of the filling point or points [21], [22], [23], [24], [25], known as the "gate," which directly affects various characteristics of the final product (geometric and mechanical), as well as the parameters during the polymer casting process into the mold-forming tool. The gate is part of the mold system of the mold-forming tool, which ensures the passage of the polymer from the mixing head (in "Liquid Composite Molding" (LCM) technologies) or the chamber with the melted material, in machines for standard high-temperature melt injection, into the molding cavities.

From the perspective of mold making, incorrect positioning or number of gates can lead to an exponential increase in tool correction costs, production process delays, and loss of potential profits.

Incorrect determination of parameters leads to several consequences, such as:

- Change in process pressure;
- Incomplete mold filling;
- Appearance of weld lines, contributing to reduced mechanical properties of the product;
- Different polymer shrinkage – deviations in dimensions and weight;
- Deformations, warping of the product;

Print ISSN 1691-5402
Online ISSN 2256-070X
https://doi.org/10.17770/etr2024vol3.8142

- Preconditions for trapping air volumes.

In continuation, the study and improvement of technologies have found various combinations to improve the filling process with control over the gates, part of them being:

- Injection of polymer simultaneously from all gates;
- Injection of polymer with progressive opening and closing of individual filling gates;
- Fixed filling pressure through all injection gates;
- Variable pressure in different filling zones.

Fig. 1 visually shows the different variations of injection, as well as the change in the melt speed during single-gate and multi-gate injection

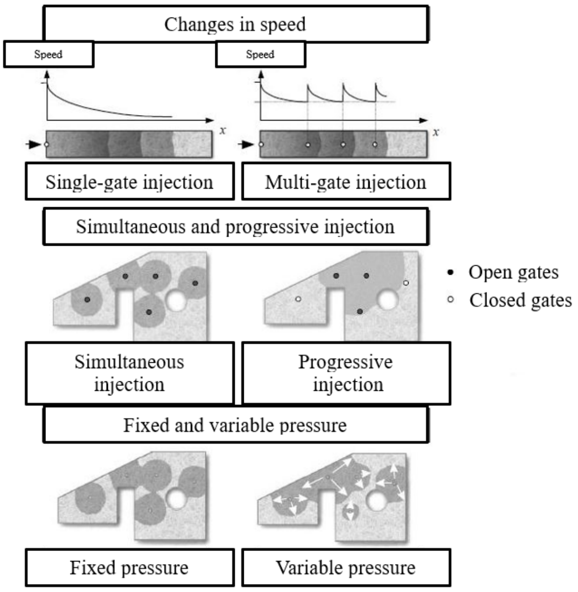

Fig. 1. Variations of injection [26].

Through the position of the injection ports and complex control over the process, it is possible to influence the direction and speed of the fluid, which affects the different characteristics of the final product [26], [27], [28], [29].

II. Materials and Methods

To conduct the study, three key stages need to be passed (Fig. 2), through which the basic geometry for analysis is created, the finite element mesh model is generated, the number and locations of the filling points are determined, material characteristics and process parameters are set.

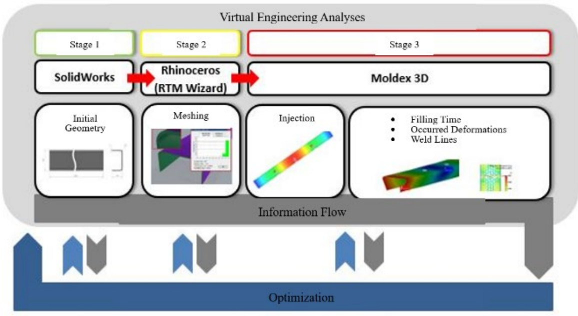

Fig. 2. Stages of creating the analysis.

A. *Stage 1 – Design of the model*

The design of the virtual object for the study was performed using the CAD software "SolidWorks", which detail was subsequently exported in a file format with the extension "STEP", to facilitate the preparation of a mesh model in the next stage (Fig. 3).

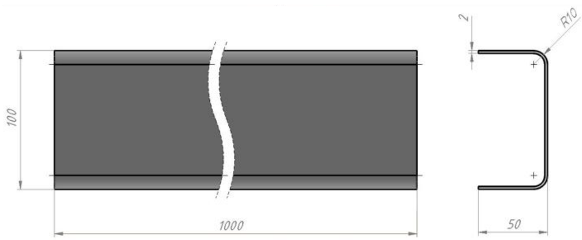

Fig. 3. CAD Model.

B. *Stage 2 – Creating a mesh model and determining the number and location of the filling points*

The construction of the finite element mesh model was carried out using the specialized software "Rhinoceros", and the available tools for this purpose, where the fiber orientation of the available preform was also determined. (Fig. 4).

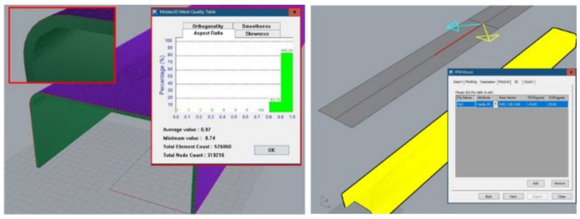

Fig. 4. Stages of building a finite element model.

The steps used in building the mesh model are:

- Importing the STEP file;
- Creating a shell mesh of finite elements;
- Merging all elements of the mesh into a unified model;
- Creating an offset of the mesh relative to the original, with a distance equal to the thickness of the designed detail;
- Building a volumetric mesh of finite elements through topological synchronization of the two surface meshes and determining the number of volumetric layers;
- Setting the fiber orientation and direction of the base vector, dividing the angle formed between the fibers into two equal halves, with the possibility to

introduce information about different fiber orientations in separate zones through the inclusion of an additional stage in the study, namely - analysis of the preform molding and the orientations created in the product;
- Positioning of the injection points in the models.

To determine the optimal position of the filling points, a set of variations is considered (Fig. 5), aiming to analyze the filling speed of the mold, the possibility of weld lines appearance, and the deformation values occurred in the detail

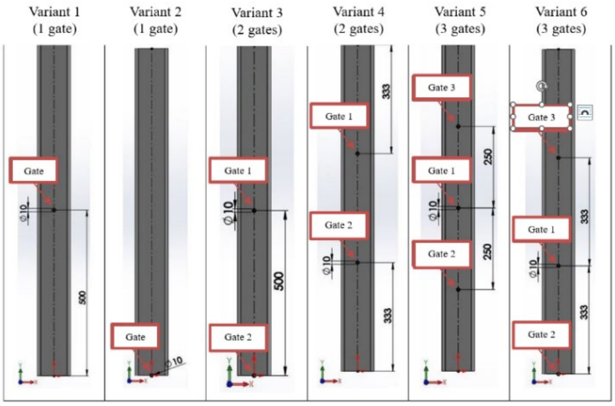

Fig. 5. Initial models for study.

C. Stage 3 - Construction of a model to analyze the influence of the number and position of injection points on the fluid flow

The exported mesh of finite elements with the introduced characteristics for fiber orientation is imported into the next tool for engineering analysis (Moldex3D), introducing material properties for the individual structural components (reinforcing structure and polymer matrix) and process settings necessary for completing the analysis.

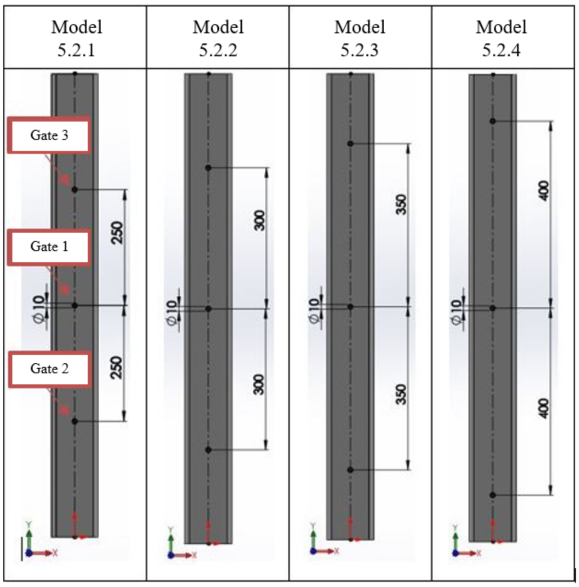

Fig. 6. Additional models for study.

After the preliminary analyses of the models and their comparison based on the selected control parameters, additional studies need to be conducted on the model with the best results, aiming to examine further similar variations in the arrangement of the injection points (Fig. 6).

III. Conclusion

A multi-step approach for conducting a virtual analysis is presented to investigate the influence of the number and position of injection gates on the quality of the final product. By using three tools in separate stages, in the creation of products through Thermoplastic Resin Transfer Molding (T-RTM) and Resin Transfer Molding (RTM) technologies, it is possible to prevent potential problems such as underfilling of the mold, the appearance of weld lines, and other defects in the technological process directly related to the injection gates.

The method of using virtual engineering analysis at the stage of designing the mold-making tool provides extremely valuable information to designers for identifying potential issues and their preemptive resolution, thereby saving resources and time in the manufacturing of tooling equipment.

By including an additional stage, a preliminary analysis of the preform molding and thus the created fiber orientations, it is possible to enrich the information flow with combined data and more accurately track the behavior of the fluid flow, the consequences arising from the set input parameters, and to pinpoint problem areas.

Acknowledgments

This work is performed by the support of project “Research of the opportunities of developing “active” safety goggles with UV-light face mask implementing functions for fast sanitizing breathing air – ACTIVE PRO UV” - КП-06-Н47/9.

References

[1] S. Hancock and L. Harper, ‘Cost, rate, and robustness’, in Design and Manufacture of Structural Composites, Elsevier, 2023, pp. 447–471. doi: 10.1016/B978-0-12-819160-6.00022-6.
[2] M. R. Mansor, S. H. S. M. Fadzullah, and A. H. Nurfaizey, ‘Life cycle assessment (LCA) analysis of composite products in automotive applications’, in Biocomposite and Synthetic Composites for Automotive Applications, Elsevier, 2021, pp. 147–172. doi: 10.1016/B978-0-12-820559-4.00005-5
[3] J. Goodsell, M. Bogdanor, and A. Favaloro, ‘Design for manufacture’, in Design and Manufacture of Structural Composites, Elsevier, 2023, pp. 349–372. doi: 10.1016/B978-0-12-819160-6.00012-3
[4] X. Lim, ‘The World Is Running Out of Elements, and Researchers Are Looking in Unlikely Places for Replacements’, Discover, May 16, 2020. [Online]. Available: https://www.discovermagazine.com/planet-earth/the-world-is-running-out-of-elements-and-researchers-are-looking-in-unlikely
[5] S. H. Han, E. J. Cho, H. C. Lee, K. Jeong, and S. S. Kim, ‘Study on high-speed RTM to reduce the impregnation time of carbon/epoxy composites’, Composite Structures, vol. 119, pp. 50–58, Jan. 2015, doi: 10.1016/j.compstruct.2014.08.023
[6] C. Gomez, D. Salvatori, B. Caglar, R. Trigueira, G. Orange, V. Michaud, ‘Resin Transfer molding of High-Fluidity Polyamide-6 with modified Glass-Fabric preforms’, Composites Part A: Applied Science and Manufacturing, no. 147, 2021
[7] E. Poodts, G. Minak, L. Mazzocchetti, and L. Giorgini, ‘Fabrication, process simulation and testing of a thick CFRP component using the RTM process’, Composites Part B: Engineering, vol. 56, pp. 673–680, Jan. 2014, doi: 10.1016/j.compositesb.2013.08.088

[8] D. Heider, 'High-Pressure Resin Transfer Molding (HP-RTM)', University of Delaware, Mar. 2019. [Online]. Available: https://nwp.engr.udel.edu/ccm/tech-briefs/2019/hp-rtm-0301.pdf
[9] L. Kärger et al., 'Development and validation of a CAE chain for unidirectional fibre reinforced composite components', Composite Structures, vol. 132, pp. 350–358, Nov. 2015, doi: 10.1016/j.compstruct.2015.05.047
[10] G. Todorov, K. Kamberov, and T. Ivanov, 'Parametric optimisation of resistance temperature detector design using validated virtual prototyping approach', Case Studies in Thermal Engineering, vol. 28, p. 101302, Dec. 2021, doi: 10.1016/j.csite.2021.101302.
[11] S. M. Afazov, A. A. Becker, and T. H. Hyde, 'Development of a Finite Element Data Exchange System for chain simulation of manufacturing processes', Advances in Engineering Software, vol. 47, no. 1, pp. 104–113, May 2012, doi: 10.1016/j.advengsoft.2011.12.011
[12] S. Bickerton, P. Šimáček, S. E. Guglielmi, and S. G. Advani, 'Investigation of draping and its effects on the mold filling process during manufacturing of a compound curved composite part', Composites Part A: Applied Science and Manufacturing, vol. 28, no. 9–10, pp. 801–816, Jan. 1997, doi: 10.1016/S1359-835X(97)00033-X
[13] V. Ganev., Ya. Dimitrova, and S. Antonov, 'Fast prototyping in the manufacturing of complex armament parts', presented at the International scientific journal 'security & future', 2018
[14] F. Trochu, E. Ruiz, V. Achim, and S. Soukane, 'Advanced numerical simulation of liquid composite molding for process analysis and optimization', Composites Part A: Applied Science and Manufacturing, vol. 37, no. 6, pp. 890–902, Jun. 2006, doi: 10.1016/j.compositesa.2005.06.003
[15] S. Soukane and F. Trochu, 'Application of the level set method to the simulation of resin transfer molding', Composites Science and Technology, vol. 66, no. 7–8, pp. 1067–1080, Jun. 2006, doi: 10.1016/j.compscitech.2005.03.001
[16] M. Y. Lin, M. J. Murphy, and H. T. Hahn, 'Resin transfer molding process optimization', Composites Part A: Applied Science and Manufacturing, vol. 31, no. 4, pp. 361–371, Apr. 2000, doi: 10.1016/S1359-835X(99)00054-8
[17] L. Kroll, 'Modeling, integrative simulation, and optimization', in Multifunctional Lightweight Structures, L. Kroll, Ed., Berlin, Heidelberg: Springer Berlin Heidelberg, 2023, pp. 563–629. doi: 10.1007/978-3-662-62217-9_8
[18] G. Todorov, B. Zlatev, and K. Kamberov, 'Digital twin definition based on virtual prototype evolution of an UPS with kinetic battery accumulator', presented at the THERMOPHYSICAL BASIS OF ENERGY TECHNOLOGIES (TBET 2020), Tomsk, Russia, 2021, p. 110008. doi: 10.1063/5.0044792.
[19] G. Todorov, K. Kamberov, H. Vasilev, and T. Ivanov, 'Design Variants Assessment Of Street LED Device Based On Virtual Prototyping', in 2021 17th Conference on Electrical Machines, Drives and Power Systems (ELMA), Sofia, Bulgaria: IEEE, Jul. 2021, pp. 1–4. doi: 10.1109/ELMA52514.2021.9503086.
[20] G. Todorov, V. Obretenov, K. Kamberov, T. Ivanov, T. Tsalov, and B. Zlatev, 'Concept and Physical Prototyping of Micro Hydropower System Using Vertical Crossflow Turbine', in 2021 6th International Symposium on Environment-Friendly Energies and Applications (EFEA), Sofia, Bulgaria: IEEE, Mar. 2021, pp. 1–4. doi: 10.1109/EFEA49713.2021.9406242.
[21] S. Jiang, C. Zhang, and B. Wang, 'Optimum arrangement of gate and vent locations for RTM process design using a mesh distance-based approach', Composites Part A: Applied Science and Manufacturing, vol. 33, no. 4, pp. 471–481, Apr. 2002, doi: 10.1016/S1359-835X(01)00146-4
[22] X. Ye, C. Zhang, Z. Liang, and B. Wang, 'Heuristic algorithm for determining optimal gate and vent locations for RTM process design', Journal of Manufacturing Systems, vol. 23, no. 4, pp. 267–277, Jan. 2004, doi: 10.1016/S0278-6125(04)80039-6
[23] M. Seyednourani, M. Yildiz, and H. S. Sas, 'A two-stage optimization methodology for gate and vent locations and distribution media layout for liquid composite molding process', Composites Part A: Applied Science and Manufacturing, vol. 149, p. 106522, Oct. 2021, doi: 10.1016/j.compositesa.2021.106522
[24] B. Liu, S. Bickerton, and S. G. Advani, 'Modelling and simulation of resin transfer moulding (RTM)—gate control, venting and dry spot prediction', Composites Part A: Applied Science and Manufacturing, vol. 27, no. 2, pp. 135–141, Jan. 1996, doi: 10.1016/1359-835X(95)00012-Q
[25] J. Wang, P. Simacek, and S. G. Advani, 'Use of Centroidal Voronoi Diagram to find optimal gate locations to minimize mold filling time in resin transfer molding', Composites Part A: Applied Science and Manufacturing, vol. 87, pp. 243–255, Aug. 2016, doi: 10.1016/j.compositesa.2016.04.026
[26] M. K. Kang, J. J. Jung, and W. I. Lee, 'Analysis of resin transfer moulding process with controlled multiple gates resin injection', Composites Part A: Applied Science and Manufacturing, vol. 31, no. 5, pp. 407–422, May 2000, doi: 10.1016/S1359-835X(99)00086-X
[27] J. M. Lawrence, P. Fried, and S. G. Advani, 'Automated manufacturing environment to address bulk permeability variations and race tracking in resin transfer molding by redirecting flow with auxiliary gates', Composites Part A: Applied Science and Manufacturing, vol. 36, no. 8, pp. 1128–1141, Aug. 2005, doi: 10.1016/j.compositesa.2005.01.024
[28] B. X. Chai et al., 'Simulation-based optimisation for injection configuration design of liquid composite moulding processes: A review', Composites Part A: Applied Science and Manufacturing, vol. 149, p. 106540, Oct. 2021, doi: 10.1016/j.compositesa.2021.106540
[29] S. Laurenzi, A. Casini, and D. Pocci, 'Design and fabrication of a helicopter unitized structure using resin transfer moulding', Composites Part A: Applied Science and Manufacturing, vol. 67, pp. 221–232, Dec. 2014, doi: 10.1016/j.compositesa.2014.09.007