EASR

Engineering and Applied Science Research

https://www.tci-thaijo.org/index.php/easr/index

Published by the Faculty of Engineering, Khon Kaen University, Thailand

The experimental study of rear fender production using plastic injection molding with Moldex3D simulation

Siwasit Pitjamit[1, 2], Parida Jewpanya*[1, 2] Pinit Nuangpirom[3, 4], Kraisorn Wongpoo[2] and Suwannee Sriyab[1]

[1]Center of Excellence, Faculty of Engineering, Rajamangala University of Technology Lanna Tak, Tak 63000, Thailand
[2]Department of Industrial Engineering, Faculty of Engineering, Rajamangala University of Technology Lanna Tak, Tak 63000, Thailand
[3]Center of Excellence, Faculty of Engineering, Rajamangala University of Technology Lanna, Chiang Mai 50300, Thailand
[4]Department of Electrical Engineering, Faculty of Engineering, Rajamangala University of Technology Lanna, Chiang Mai 50300, Thailand

Received 18 July 2023
Revised 8 October 2023
Accepted 20 October 2023

Abstract

In the automotive industry are currently getting more attention because of a significant rise in demand for plastic products, particularly in the automotive, aerospace, sports, and household markets. To produce elaborate shapes and complex geometries with good dimensional precision, manufacturers placed increased focus on plastic injection molding. Adopting various cutting-edge technologies, such as CAD/CAM/CAE, is crucial to meeting demand since they help us understand the injection molding process and manufacture high-quality products. This article focuses on the analysis of the rear fender for automotive products used in the injection molding process using the software Moldex3D. One of the various types of software used to simulate a component's model is Moldex3D. Software called Moldex3D is commonly referred to as computer-aided engineering (CAE). According to the material and technological factors utilized, determines the melt front time, and sprue pressure. Polypropylene (PP) material has been taken into consideration in current research. The qualities of plastic products are influenced by a variety of factors. According to the investigation, the most suitable gate position for a consistent flow of mold material has been suggested. The injection speed and injection pressure are factors that affect the melt front time, according to the multilevel factorial design. To generate the best quality product, the operational factors must be accurate. With a change in parameters, there are changes in the product. The quality of manufacturing products without defects such improper location of runner, flow marks, short shots, hesitation, over packing, and others are referred to as the optimal parameter.

Keywords: Injection molding, Simulation, Experimental design, Rear fender production

1. Introduction

Because of their versatility in design, ability to reduce weight, durability, resilience, and corrosion resistance, plastics are utilized to create automobile products in a cost-effective way. Thus, the use of a tool and die manufacture in plastic injection has rapidly expanded because of the continued development of improved, high-performance polymers. Due to the high cost and labor-intensive nature of mold design and manufacture, simulations are required to evaluate and create complicated plastic objects. This improves output and uniformity of the process. The evolution of computer-aided engineering (CAE) technology, particularly Moldflow analysis, has made it possible to produce high-quality products with fewer mold trials. Nonetheless, the most challenging aspects of using this program are optimizing the design and comprehending the operation of the hot runners during the injection molding process. To enhance the quality of the final product, numerous researchers have tried to assess and develop the mold.

To determine how the sink mark index of plastic injection molded components was impacted by mold temperature, melt temperature, holding pressure, cooling time, and injection time. Martowibowo and Kaswadi [1] employed Moldflow software. A viable tool design methodology for an injection mold for combining links was provided by Mate and Kadlag [2]. The material used for connecting linkages in this investigation is polyacetal. The work also shows how factors like air traps, fill time, sink marks, weld line and others have impacted the final product's quality. Guerrier et al. [3] evaluated the effectiveness of using Moldex3D in the design and optimization of automotive parts. The study simulated the injection molding process of a bumper and compared the results with the actual part produced. The simulation results showed good agreement with the actual part, and the study demonstrated the potential of Moldex3D for improving part quality and reducing production costs. Kitayama et al. [4] investigated the optimization of the injection molding process parameters for producing a dashboard panel in the automotive industry. The study used Moldex3D to simulate the molding process and evaluate the effects of various parameters such as injection speed, packing pressure, and cooling time. The results showed that the optimized parameters could significantly improve the part quality and reduce the manufacturing defects. Huang et al. [5] conducted a study on the simulation of micro-injection molding processes using injection molding simulation software. The study simulated the molding process of micro-gears and evaluated the effects of various parameters such as mold temperature, injection

*Corresponding author.
Email address: parida.jewpanya@rmutl.ac.th
doi: 10.14456/easr.2023.67

pressure, and packing time. The results showed that the simulation software could accurately predict the filling behavior and cooling characteristics of the micro-gears and suggest optimal process parameters for achieving high-quality parts. Li et al. [6] conducted a study on the simulation of multi-component injection molding processes using Moldex3D. The study simulated the overmolding process of a plastic and metal part in the automotive industry and evaluated the effects of different process parameters. The results showed that Moldex3D could accurately predict the potential manufacturing defects and suggest optimal process parameters for achieving high-quality parts.

The discussed articles present a wealth of insights into optimizing injection molding processes and related technologies. Tian et al. [7] uncovers a crucial relationship between extrusion temperatures and load evolution, revealing that higher temperatures lead to decreased extrusion loads. Kuo et al. [8], the integration of metal additive manufacturing for injection molds with conformal cooling channels is demonstrated, showcasing its potential to enhance cooling efficiency and reduce production costs. Kuo and Qiu [9] exhibits the successful implementation of a method that substantially reduces coolant leakage, enhances mold properties, and significantly cuts down on production time and costs in Direct Metal Printing (DMP) for injection mold manufacturing. Zhao et al. [10] highlights the importance of optimizing process parameters to minimize warpage and shrinkage deformations, thus enhancing the overall quality of plastic products in the injection molding process. Lastly, Kitayama [11] reviews the application of metamodel-based optimization in plastic injection molding (PIM), showcasing how it enables determining the most effective process parameters, ultimately contributing to lightweight, high gloss plastic products through an efficient and systematic approach. Collectively, these studies offer valuable insights and methodologies that can revolutionize the field of injection molding, ensuring better quality and cost-effectiveness in manufacturing processes.

According to the literature, there hasn't been as much work done on designing and manufacturing the rear fender as there has been on optimizing processes and techniques for the injection molding process. This study employed CAD software Siemens NX to develop a mold to produce rear fenders parts, which are a component of assemblies used in motorcycles. Using an experimental design by the Minitab software and Moldflow analysis was carried out on the rear fender parts to identify the molding defects and to ascertain the main effect and interactions among the variables. The factors were injection speed and injection pressure. A 3D simulation provides detailed information regarding the melt front time and to reduce development time and costs. The research framework is shown in Figure 1.

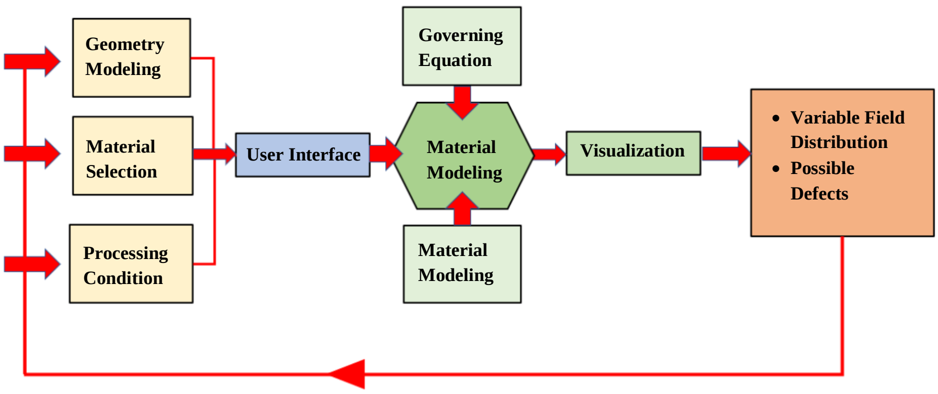

Figure 1 The research framework of plastic flow simulation for injection molding

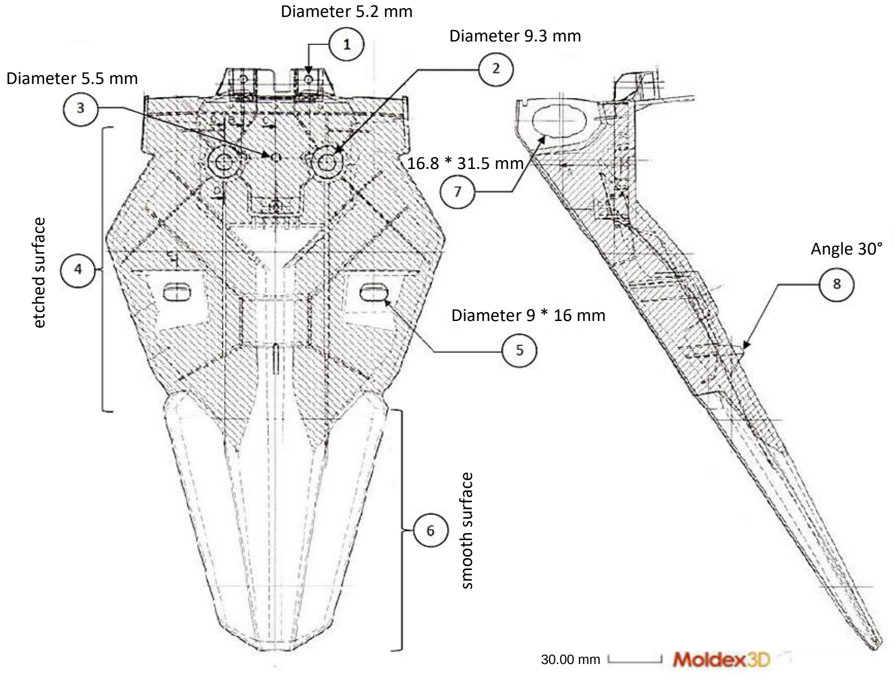

Figure 2 Modeling of Rear Fender with scale bar and unit.

2. Materials and methods

This study presents the modeling and simulation of the rear fender utilizing the plastic injection molding method. The part modeling process is made easier by NX 12 software. The use of synchronous technology supports analytical models that use multiple CAD geometries. After part modeling, the NX 12 file must be imported into Moldex3D to simulate the part model. Moldex3D offers significant results after part simulation, including melt front time, melt front temperature, maximum temperature, sprue pressure, etc.

2.1 Geometry modeling of rear fender

Due to a special request from the Company (Bangkok Diecasting and Injection Co., Ltd), a 3D model of the vehicle part (Rear Fender) has been created in Siemens NX 12. (Figure 2).

2.2 Material selection for the rear fender

A critical design factor for any vehicle part is the proper material selection. Polypropylene POLIMAXX 1100NK grade [12], a homopolymer for injection molding process, having a melt flow index (MFI) of 11 g.10 min^{-1} (230°C/ 2.16 kg) and a density of 0.9 g/cm^{-3} was supplied as pellets by IRPC Public Company Limited. In this study, a thermoplastic material that is well-known for its excellent impact resistance and toughness has been employed. Moreover, it offers outstanding scratch resistance, stiffness, and excellent dimensional stability. PP is a material with a low melting point and a low cost. PP is a thermoplastic material that lends itself well to plastic injection molding. Viscosity is an important property in fluids which can be considered as the resistance of flow. In polymers, melt temperature and shear rate will influence the value of viscosity. The viscosity is constant at low shear rate, and decreases with increasing shear rate. Also, the viscosity decreases as temperature increases. The Moldex3D manual suggests that the PP viscosity ratio should be between 0.5 and 5 ml/g. Viscosity can vary based on several factors, including temperature, shear rate, and the specific production batch. Viscosity is typically measured in terms of melt flow rate or melt mass flow rate. The properties of Polypropylene POLIMAXX 1100NK are listed in Table 1 as shown.

Table 1 Properties of Polypropylene POLIMAXX 1100NK

Properties	Value	Unit
Density	0.90	g/cm^3
Mold Temperature	40 - 60	ºC
Holding Pressure	Relative to injection pressure	MPa
Injection speed	Low to medium	cm^3/sec

Table 2 Explanation of the process parameters

Parameters	Description	Unit
Plastic	PP	-
Grade	PP 1100NK	-
Grade flow	Low flow	-
Melt temperature (min)	190	ºC
Melt temperature (normal)	215	ºC
Melt temperature (max)	240	ºC
Freeze temperature	105	ºC
Ejection temperature	70	ºC
Mold temperature (min)	40	ºC
Mold temperature (normal)	50	ºC
Mold temperature (max)	60	ºC
Shrinkage allowance	0.4	%

2.3 Processing condition

When creating any product, it is essential to classify the essential parameter because it has an impact on the product's effectiveness and quality. It has been established that the melting front temperature, freezing temperature, ejection temperature and mold temperature all significantly affect the steps involved in injection molding. The descriptions of the procedure parameters are shown in Table 2.

The rear fender parts' surfaces are converted into two shell meshes to maintain uniformity between the external mesh surfaces and ensure the filling pattern's reliability. In every shell mesh, there is a binding element between every pair of facing components. The multi-laminate approach was used to conduct Finite Element Analysis (FEA) on fusion mesh to estimate temperature and flow profiles at various locations throughout the cavity thickness. Aligned elements on opposite surfaces of a part that are mesh-matched throughout the thickness. The mesh components on the two surfaces were aligned in a way that they appeared to be part of a single mesh. Mesh modeling improved the calculation of thickness results along the section for warpage analysis and asymmetrical flow fronts. As a result, the barrier between design and analysis was removed thanks to the direct interface that the fusion technology built between CAD systems and CAE software. It was not necessary to identify the mid-plane geometry that accurately resembled a 3D model, which allowed for quick mesh production. Additionally, the final models' level of detail was increased, producing more accurate mesh models. One disadvantage was that fusion meshes had twice as many elements as mid-plane meshes of the same size, which prolonged the solution time. After that, the 12,344 elements in the fusion meshes for the rear fender part were generated with an average triangle aspect ratio of 2.08. More than 90% of the models meshes matched the original data.

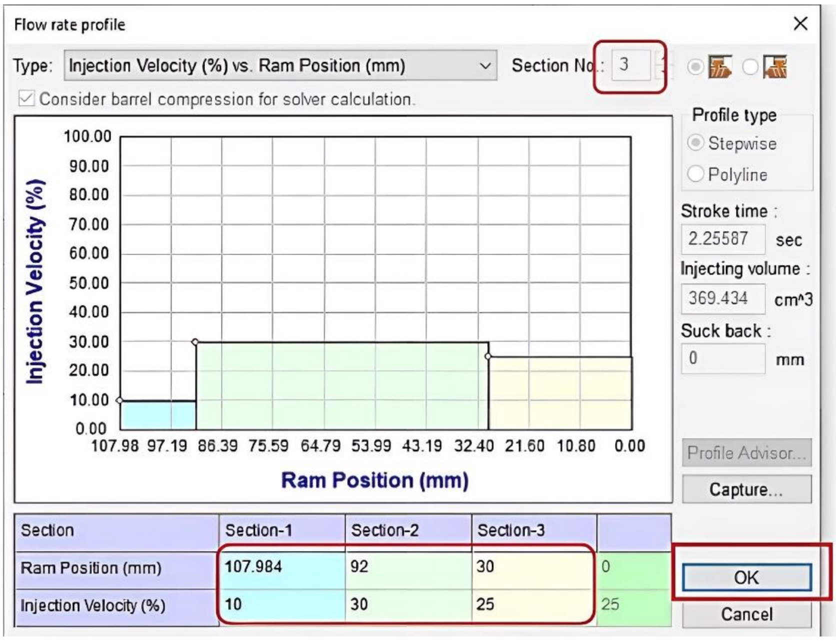

Figure 3 Filling and packing setting.

To achieve a preliminary process assessment, filling and packing analyses were carried out (Figure 3). The polymer material was POLIMAXX 1100NK from PP plastics. An injection molding machine (JSW Hiroshima plant: J450EL II:1400H) with a clamping force equal to 4420 kN and flow rate equal to 160 cm^3/sec was used. By employing a single mold with a single cavity, Repetition of the filling and packing processes. The same process parameters used in the prior analyses were used in the FEA simulations, and the flow rate was set to 160 cm3/sec. The full feeding system, which consists of one hot runner manifold feeding a gate placed back the rear fender part, was included in the FEA model. The placement of gates in the ideal cavities was made possible by the hot runners. The number of scraps decreased, and the length and diameter of each runner were the same for the mold cavity. The filling stage of single cavity is shown in Figure 4 for different filling steps.

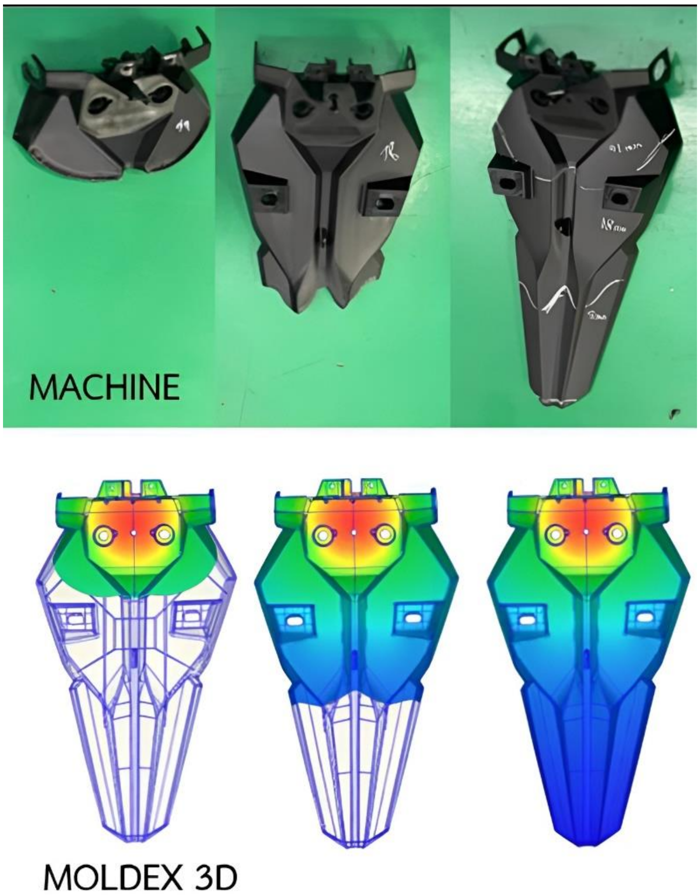

Figure 4 Filling phase

2.4 Experimental design

The experimental design using the Minitab 19 (Minitab, Ltd., Coventry, UK) multilevel factorial design technique commonly identifies statistically significant variables in a variety of applications. According to this study, the melt front time's effect was assessed using the three levels of the experimental design. The experimental boundary of the factors injection speed (A), and injection pressure (B) with two replications. To identify the most suitable boundary condition with the optimal melt front time, 16 different combinations of experimental conditions were created and shown in Table 3.

Table 3 Multilevel factorial design of relevant factors and their levels

Factors	Levels			Unit
	Low	Middle	High	
Injection speed	30	50	80	cm^3/sec
Injection pressure	50	70	90	MPa

In this context, injection speed and injection pressure are important parameters that influence the molding process and the quality of the molded parts.

Injection speed refers to the rate at which the molten material (typically plastic) is injected into the mold during the injection molding process. It is usually measured in cubic centimeters per second (cm^3/sec) or cubic inches per second (in^3/s). The injection speed is a critical parameter as it affects the flow behavior of the material within the mold, the filling time, and the final properties of the molded part.

- High Injection Speed: High injection speeds can help achieve faster filling times, reduce cycle times, and prevent early freezing of the material. However, excessively high injection speeds can lead to issues such as material degradation, excessive shear, and instability in the molding process.
- Low Injection Speed: Lower injection speeds may be necessary for certain materials or molds to avoid issues like air entrapment, excessive pressure drop, or flow hesitation. It may also be used to control shear forces on delicate or complex geometries.

Injection pressure is the amount of force applied to the material to push it into the mold cavity during the injection molding process. It is typically measured in pounds per square inch (psi) or megapascals (MPa).

- High Injection Pressure: High injection pressure is often needed to fill the mold completely, especially for molds with complex geometries or long flow paths. Higher pressure helps overcome resistance in the mold and achieve proper filling. However, excessively high pressure can cause issues like flashing, excessive stress on the mold, and higher energy consumption.
- Low Injection Pressure: Lower injection pressure may be used for simpler molds or to reduce stress on the mold and equipment. However, insufficient injection pressure may lead to incomplete filling of the mold, resulting in short shots or inadequate part quality.

In Moldex3D simulations, adjusting injection speed and pressure allows for a thorough analysis of how these parameters impact the filling behavior, part quality, and potential issues during the injection molding process. The goal is to optimize these parameters to achieve a well-filled, defect-free molded part within the specified cycle time and with optimal material usage.

2.5 Flow equations

The formulas for the governing equations [13] the laminar flow of liquid (melt) and pseudo-fluid (air) are as follows.

$$0 = -\nabla p + \nabla \cdot \left(2\eta_l u\right) + \rho g$$
$$\nabla \cdot u = 0 \; on \; \Omega_l \tag{1}$$

$$\rho_l C_{pl}\left(\frac{\partial T}{\partial t} + u \cdot \nabla T\right) = \nabla \cdot (k_t \nabla T) + 2\eta_l u$$
$$0 = -\nabla p + \nabla \cdot (2\eta_g u)$$
$$\nabla \cdot u = 0 \; on \; \Omega_g \tag{2}$$
$$\rho_g C_{pg}\left(\frac{\partial T}{\partial t} + u \cdot \nabla T\right) = \nabla \cdot (k_g \nabla T)$$

with:

$$u = \frac{1}{2}(\nabla u + (\nabla u)^T) \tag{3}$$

In the above equations t, u, p, ρ and η denote time, velocity, pressure, density, and viscosity respectively. If the velocity is zero in some portions of Ω Subscripts l and g refer to liquid and air respectively.

The problem's statement is completed by suitable boundary conditions:

$$u = u_0 \; on \; \Gamma_{inlet}$$
$$\sigma(u) \cdot n - \rho n = t \; on \; \Gamma_{traction} \tag{4}$$
$$u = 0 \; on \; \Gamma_{wall}$$

The boundary condition on Γ_wall is imposed only on the polymer melt. The research team assumes that the stresses on the interface have minimal influence on the flow because the density and dynamic viscosity of the air is significantly lower than those of the liquid. Surface stresses on the free surface are therefore disregarded. Airflow in the mold's empty zone is thought to be incompressible.

Moreover, we assume that the air can exit the mold without constraints so that the pressure on the interface remains approximately atmospheric. Consequently, a "pseudo-fluid" with the properties assumes the place of air in the numerical analysis. Moldex3D adopts a set of fundamental equations and models to simulate the injection molding process accurately. These equations are based on fluid dynamics principles and are fundamental to predicting the behavior of molten material during filling and solidification within a mold. The key equations and principles include Navier-Stokes Equations, Continuity Equations, Momentum Equations, Energy Equation, Constitutive Equations, and Material Models.

3. Results

3.1 Analysis of variance (ANOVA)

Table 4 shows the melt front time obtained by running the simulation model under various testing conditions. The analysis of variance (ANOVA) displayed in Table 5 determined the relative significance of each main factor. To assess the dataset's fit, R-squared, and adjusted R-squared statistics were also examined. Additionally, each main effect and its interaction were considered statistically significant if the p-value was less than 0.05. The analysis shows injection speed (A), and injection pressure (B). The melt front time was influenced by the interplay of variables A and B.

The R^2 result demonstrates that the model explains 99% of the variance in the melt front time, demonstrating that the model effectively fits the data. The residual plot of the melt front time and the normal probability plot of the residuals are shown in Figure 5 respectively. In the residual plots, the response's residuals randomly dispersed toward zero. The observation points (blue dots) randomly dispersed in the normal probability plot indicate that the process parameters in this investigation were normal and independently distributed when comparing the residuals to the fits. The histogram of the residuals is approximately symmetric. Regarding the residuals versus the order, the residuals exhibit no clear pattern.

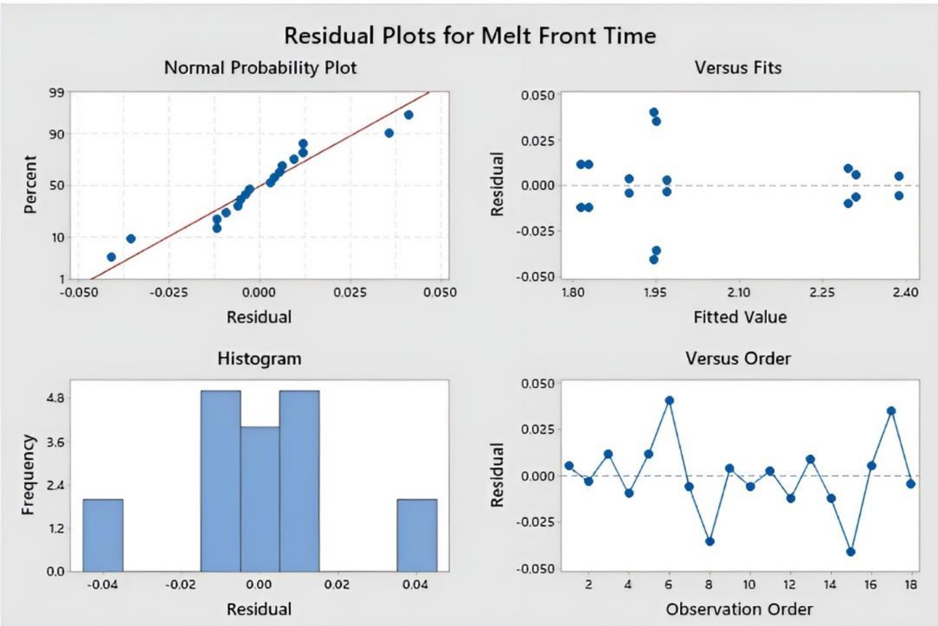

Figure 5 The residual plot of melt front time.

The Pareto chart in Figure 6 was used to quantify an effect's size and significance. The Pareto chart displays the absolute values of the standardized effects in order of largest to smallest.

Table 4 Simulation model of Rear Fender plastic injection molding results for the testing conditions

Condition	A (cm^3/sec)	B (MPa)	Melt front time. (sec)
1	30	50	2.395
2	30	70	1.966
3	30	90	1.841
4	50	50	2.288
5	50	70	1.825
6	50	90	1.986
7	80	50	2.304
8	80	70	1.914
9	80	90	1.906
10	30	50	2.384
11	30	70	1.972
12	30	90	1.817
13	50	50	2.307
14	50	70	1.801
15	50	90	1.904
16	80	50	2.316
17	80	70	1.985
18	80	90	1.098

The standardized effects are t-statistics that examine whether the effect is zero, which is the null hypothesis. The factors B, AB, and A are represented by bars in this Pareto chart that cross the reference line at 2.26. With the present model terms, these factors are statistically significant at the 0.05 level. Each factor's infection order within the chosen range is B>AB >A.

Table 5 Analysis of variance (ANOVA) for Melt front time.

Source	DF	Adj. SS	Adj.MS	FValue	PValue
Model	8	0.796973	0.099622	131.44	0.000
Linear	4	0.750877	0.187719	247.67	0.000
A	2	0.006519	0.003260	4.30	0.049
B	2	0.744358	0.372179	491.04	0.000
2-way interactions	4	0.046069	0.011524	15.20	0.000
A*B	4	0.046096	0.011524	15.20	0.000
Error	9	0.006822	0.000758		
Total	17	0.803795			
R-sq = 99.15%			**R-aq (adj) = 98.40%**		

According to the statistical model study, it also means that variable B is possibly the most significant. The relationship between variables A and B is the second most significant factor. Variable A's impact on the melt front time ranks third.

The optimal condition according to the response optimizer function in Figure 7 showed that the optimal conditions for the melt front time were injection speed of 30 cm^3/sec and injection pressure of 50 MPa resulting in the melt front time of 2.389 sec.

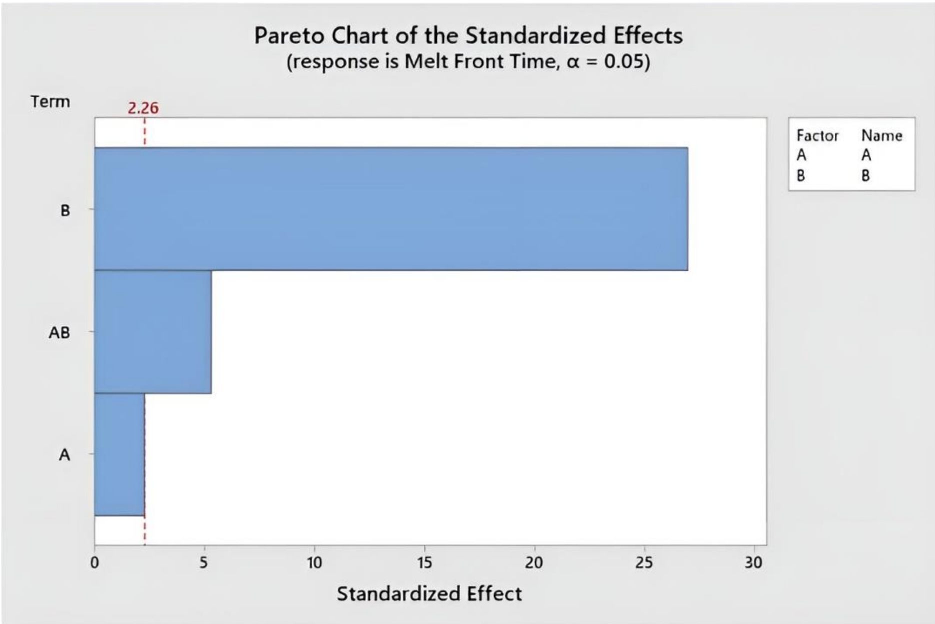

Figure 6 Pareto chart of the effect of melt front time

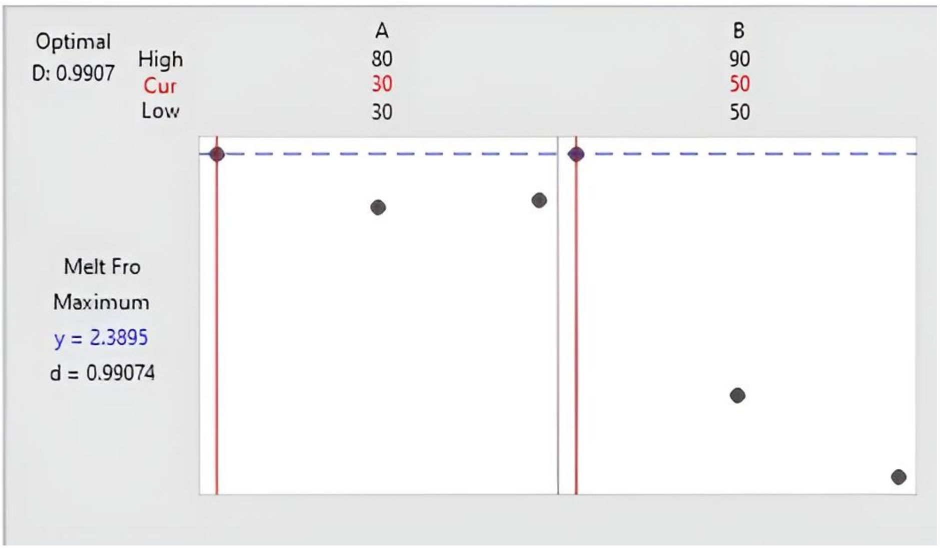

Figure 7 Optimal condition of experimental boundary

3.2 Position of gate

The most suitable location for the gate is shown in Figure 8. The choice of the gate position is one of the crucial factors since it affects the injection molding process's mold temperature distribution and cuts down on filling time. This paper used a trial-and-error approach to determine the most suitable location for the gate by placing it in several locations.

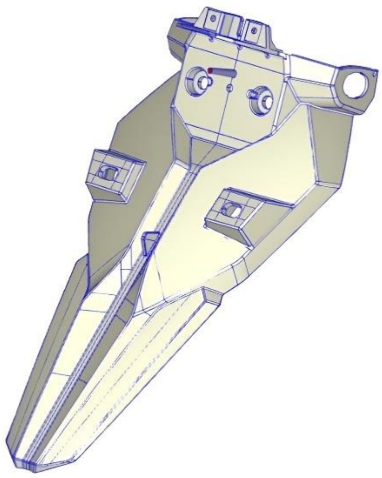

Figure 8 Location of gate

Verifying the most suitable gate location in injection molding involves a comprehensive evaluation based on various criteria, considering factors such as mold temperature distribution, filling time, part quality, material flow, and potential defects. Combining simulation analysis, physical experiments, and iterative adjustments, to verify and confirm the most suitable gate location for the injection molding process, ultimately optimizes the production of high-quality parts.

3.3 Melt front time

A further important consideration in achieving balanced gate contributions is the melt front time. To minimize hesitation, all flow paths should arrive at the cavity wall at the same time. It displays the skin material's melt front position regarding time during the filling stage. To minimize hesitancy during the injection process, it is crucial to select the appropriate factors, such as the melt flow index, injection flow rate, change gate location, and mold temperature. The product shown in Figure 9 is subjected to several flow analyses to determine the most suitable for the gate. The red area shows the shortest time between 0.061 and 2.395 sec. needed to fill the pattern geometry, and the blue area indicates the longest time required between 2.084 and 2.395 sec. If there are any issues with the part, such as hesitation, the geometry demonstrates it without any color.

The melt front time result shows where the melt front was in relation to time during the filling step. The balanced flow contribution of the gate should be visible in an optimum melt front time result, and all flow paths should simultaneously reach the cavity wall. It is the outcome of injection molding that is most useful. The following studies corroborated potential problems that could be inferred from the melt front time: Hesitation [14], Short Shot [15], and Overpacking [16].

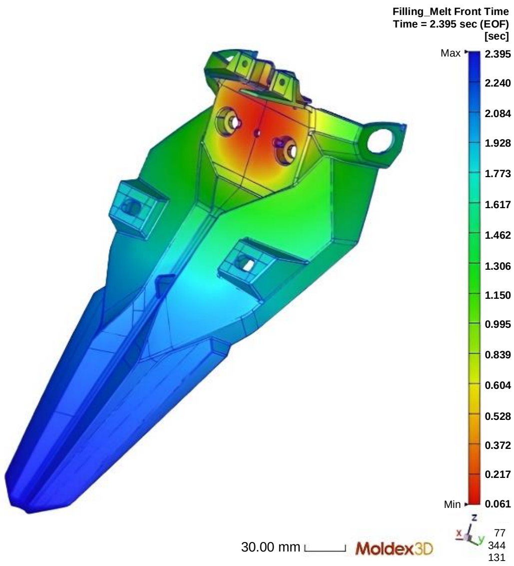

Figure 9 Melt front time for location of gate (optimum)

3.4 Melt front temperature

The melt front temperature refers to the temperature of the molten plastic material as it flows through the mold during the injection molding process. This temperature is a critical factor that can affect the quality of the final molded product. Understanding the melt front temperature is essential to avoiding problems with flow marks, weld lines, hesitation, and material degradation during the injection molding process. Figure 10 illustrates the Moldflow process producing ripples at the gate. The analysis has a uniform distribution of the melt front temperature. The temperature is maintained throughout the process at up to 214 °C, except for the top of the rear fender pieces, when it drops to between 207 and 209 °C. Due to the process's high temperature, issues such as material degradation are not observed.

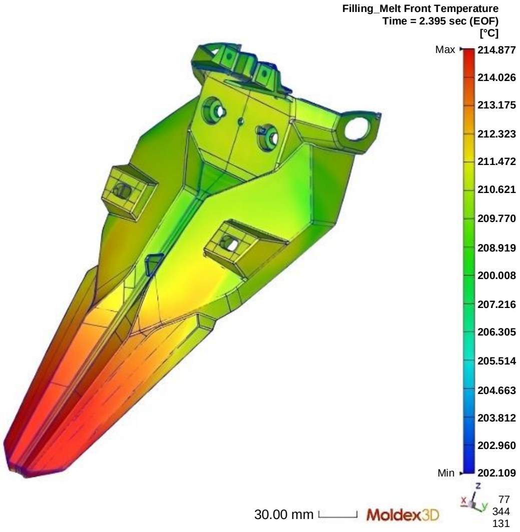

Figure 10 Melt front temperature (optimum)

The melt front temperature result displays the melt temperature value that was recorded as soon as it arrived at the position that was visible. The temperature readings displayed in this result possibly do not all belong to the same time step. Determine the following injection molding research based on the melt front temperature: weld line [17], flow mark [18], hesitation [19], and material degradation due to high temperature [20].

3.5 Filling spure pressure

To minimize issues including material degradation and overpacking that are brought on by an uneven pressure distribution, it is important to evaluate the filling sprue pressure, which displays an appropriate distribution of pressure throughout the part as shown in Figure 11. At the runner section, there is a rapid increase in pressure, the pressure is constant, as indicated by the color red. The non-uniform distribution of pressure can be reduced by choosing the appropriate gate size and runner location. The pressure values found in this analysis range from a minimum of 0.0 to 9.6 MPa, which is shown in green, Maximum of 19.2 to 38.4 MPa, which is shown in red.

The plot of sprue pressure versus filling time is displayed in the filling sprue pressure result. As a result, it's important to observe for any unusual sprue pressure increases during filling. The maximum permitted injection pressure, which is set in the process condition, is frequently not exceeded by the sprue pressure. Hesitation or even a short shot might occur if the resulting sprue pressure curve remains at the maximum permitted injection pressure. This is in line with the findings of Huang et al.'s research [21].

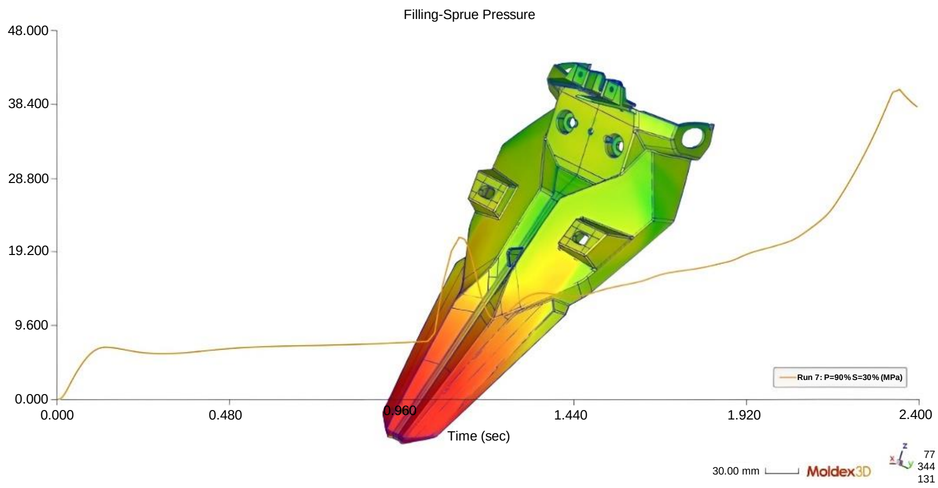

Figure 11 Filling Sprue Pressure (optimum)

4. Discussion

Melt front time is an important parameter in injection molding simulation, and Moldex3D is a well-known software used for simulating the injection molding process. There have been several research studies that have investigated the accuracy of Moldex3D in predicting melt front time. From the experimental results, it was found that the melt front time from the actual injection molding experiment (Figure 4) under the optimal conditions was not different from the simulation results, consistent with the research of Tsai and Liao [22]. This research compared the predicted and actual melt front times for an injection molding process using Moldex3D. The researchers found that it was able to accurately predict the melt front time for the process, with an error of less than 5%. Islam et al. [23] compared the predicted and actual melt front times for a different injection molding process using Moldex3D. The researchers found that Moldex3D was able to predict the melt front time with an error of less than 4% and concluded that Moldex3D is a reliable tool for simulating melt front time in injection molding.

Research related to melt front temperature typically involves studying the behavior of molten materials during processes like injection molding or other forms of material processing. This research aims to understand how temperature variations in the molten material impact the final product's quality, structural integrity, and other relevant factors. Bledzki and Faruk [24] investigated the effect of melt front temperature on the mechanical properties of an injection-molded polypropylene part. The researchers found that increasing the melt front temperature resulted in a decrease in the tensile strength and modulus of the molded part. They also found that the melt front temperature had a significant effect on the surface roughness and glossiness of the molded part. Solanki et al. [25] investigated the effect of melt front temperature on the shrinkage and warpage of an injection-molded part. The researchers found that increasing the melt front temperature resulted in higher levels of shrinkage and warpage, which can affect the dimensional accuracy of the final product.

Filling sprue pressure is another important parameter in the injection molding process that can affect the quality and properties of the final product. Liparoti et al. [26] studied the effect of filling sprue pressure on the mechanical properties of an injection-molded polypropylene part. The researchers found that increasing the filling sprue pressure resulted in a significant improvement in the tensile strength and modulus of the molded part. They also found that higher filling sprue pressure reduced the porosity of the part, which can improve its mechanical properties. Huang et al. [27] researched the effect of filling sprue pressure on the warpage of an injection-molded part. The researchers found that increasing the filling sprue pressure resulted in a reduction in the warpage of the molded part. They also found that the filling sprue pressure had a significant effect on the filling time and melt front velocity during the injection molding process.

Overall, these studies suggest that Moldex3D is a reliable tool for simulating melt front time, melt front temperature, and sprue pressure in injection molding. However, it is important to note that the accuracy of the simulation also depends on the quality of the input data, including the material properties and mold geometry. Designers should ensure that they have accurate input data to obtain reliable results from the simulation.

5. Conclusions

It is essential to analyze the flow factors that affect product quality. Some of these factors are melt front time, filling time, pressure drop, melt front temperature, runner location, air traps, and weld lines. A simulation-based analysis for the influence of process parameters, injection speed, and injection pressure, on pattern is performed. According to the simulation and experimental results, the optimal conditions for the melt front time were an injection speed of 30 cm^3/sec and an injection pressure of 50 MPa resulting in the melt front time of 2.389 sec. In this study, the part is attentively analyzed, and the number of trials is determined by adjusting the various factors using Moldflow analysis, which includes the melt front temperature, sprue pressure, and maximum temperature. It also assists the mold designer to develop the optimal mold for plastic injection molding with the minimum possible defects. In the future, to prevent injection molding issues when manufacturing parts for the automobile industry, for example flow marks, poor surface uniformity, hesitation, and short shots will be evaluated.

6. Acknowledgements

The research team would like to thank Mr. Peerapak Kaewsen and Mr. Nuttawut Tana from Bangkok Diecasting and Injection co. ltd. (BDI Group) that assisted in providing data and conducting the experiment. This work was supported by BDI Group under MOU between Rajamangala University of Technology Lanna (RMUTL) and BDI group.

7. References

[1] Martowibowo SY, Kaswadi A. Optimization and simulation of plastic injection process using genetic algorithm and moldflow. Chin J Mech Eng. 2017;30(2):398-406.
[2] Mate SD, Kadlag VL. Design and mould Flow Analysis of Injection mould for Luggage Bag Wheel-A Review. Int J Res Emerg Sci Technol. 2016;3(1):12-15.
[3] Guerrier P, Tosello G, Nielsen KK, Hattel JH. Three-dimensional numerical modeling of an induction heated injection molding tool with flow visualization. Int J Adv Manuf Technol. 2016;85:643-60.
[4] Kitayama S, Tamada K, Takano S, Aiba S. Numerical and experimental investigation on process parameters optimization in plastic injection molding for weldlines reduction and clamping force minimization. Int J Adv Manuf Technol. 2018;97:2087-2098.
[5] Huang CT, Hsu YH, Chen BH. Investigation on the internal mechanism of the deviation between numerical simulation and experiments in injection molding product development. Polym Test. 2019;75:327-36.
[6] Li SS, Yan B, An H. Study on effect of mold temperature on PP-foamed injection-molded products based on moldex3D analysis. China Plast. 2019;31(1):53-8.
[7] Tian Y, Hu H, Zhang D. A novel severe plastic deformation method for manufacturing Al/Mg bimetallic tube. Int J Adv Manuf Technol. 2021;116:2569-75.
[8] Kuo CC, Xu JY, Zhu YJ, Lee CH. Effects of different mold materials and coolant media on the cooling performance of epoxy-based injection molds. Polymers. 2022;14(2):280.

[9] Kuo CC, Qiu SX. A simple method of reducing coolant leakage for direct metal printed injection mold with conformal cooling channels using general process parameters and heat treatment. Materials. 2021;14(23):7258.
[10] Zhao NY, Lian JY, Wang PF, Xu ZB. Recent progress in minimizing the warpage and shrinkage deformations by the optimization of process parameters in plastic injection molding: a review. Int J Adv Manuf Technol. 2022;120:85-101.
[11] Kitayama S. Process parameters optimization in plastic injection molding using metamodel-based optimization: a comprehensive review. Int J Adv Manuf Technol. 2022;121:7117-45.
[12] Kuntiwong K. Effects of thickness of the flow channel, melt temperature and mold temperature on the flow behavior of polypropylene/silicon carbide composites using injection molding simulation. SNRU J Sci Technol. 2018;10(1):58-65.
[13] Hétu JF, Gao DM, Garcia RA, Salloum G. 3D Finite element method for the simulation of the filling stage in injection molding. Polym Eng Sci. 1998;38(2):223-36.
[14] Grabowski Ł, Baier A, Majzner M, Sobek M. Composite materials molding simulation for purpose of automotive industry. IOP Conf Ser: Mater Sci Eng. 2016;145(2):022023.
[15] Cao W, Kong L, Li Q, Ying J, Shen C. Model and simulation for melt flow in micro-injection molding based on the PTT model. Modelling Simul Mater Sci Eng. 2011;19(8):085003.
[16] Wang BW, Nian SC, Huang MS. Strategies for adjusting process parameters in CAE simulation to meet real injection molding condition of screw positions and cavity pressure curves. Int J Adv Manuf Technol. 2022;122(3-4):1339-51.
[17] Kovács JG, Sikló B. Experimental validation of simulated weld line formation in injection moulded parts. Polym Test. 2010;29(7):910-4.
[18] Otmani RE, Zinet M, Boutaous M, Benhadid H. Numerical simulation and thermal analysis of the filling stage in the injection molding process: role of the mold-polymer interface. J Appl Polym Sci. 2011;121(3):1579-92.
[19] Regi F, Guerrier P, Zhang Y, Tosello G. Experimental characterization and simulation of thermoplastic polymer flow hesitation in thin-wall injection molding using direct in-mold visualization technique. Micromachines. 2020;11(4):428.
[20] Yang X, Bai Q, Guo Z, Niu Z, Yang C, Jin L, et al. Comparison of direct numerical simulation with volume-averaged method on composite phase change materials for thermal energy storage. Appl Energy. 2018;229:700-14.
[21] Huang ZM, Kim HM, Youn JR, Song YS. Injection molding of carbon fiber composite automotive wheel. Fibers Polym. 2019;20:2665-71.
[22] Tsai HH, Liao YL. Feasibility Study of the flatness of a plastic injection molded pallet by a newly proposed sequential valve gate system. Polymers. 2022;14(3):616.
[23] Islam A, Li X, Wirska M. Injection moulding simulation and validation of thin wall components for precision applications. In: Gapiński B, Szostak M, Ivanov V, editors. Advances in Manufacturing II. Cham: Springer; 2019. p. 96-107.
[24] Bledzki AK, Faruk O. Effects of the chemical foaming agents, injection parameters, and melt-flow index on the microstructure and mechanical properties of microcellular injection-molded wood-fiber/polypropylene composites. J Appl Polym Sci. 2005;97(3):1090-6.
[25] Solanki BS, Sheorey T, Singh H. Experimental and numerical investigation of shrinkage and sink marks on injection molded polymer gears: a case study. Int J Interact Des Manuf. 2022;16(4):1653-67.
[26] Liparoti S, Speranza V, Sorrentino A, Titomanlio G. Mechanical properties distribution within polypropylene injection molded samples: effect of mold temperature under uneven thermal conditions. Polymers. 2017;9(11):585.
[27] Huang MS, Nian SC, Lin GT. Influence of V/P switchover point, injection speed, and holding pressure on quality consistency of injection-molded parts. J Appl Polym Sci. 2021;138(41):51223.