Simulation Based Optimization of Thin Wall Injection Molding Parameter Using Response Surface Methodology

M. U. Rosli1, S. N. A. Ahmad Termizi1, C. Y. Khor1, M. A. M. Nawi1, Ahmad Akmal Omar1 and Muhammad Ikman Ishak1

1Simulation and Modelling Research Group (SimMReG), Faculty of Engineering Technology, Universiti Malaysia Perlis (UniMAP), Kampus UniCITI Alam, Sungai Chuchuh, Padang Besar, 02100 Perlis, Malaysia.

E-mail: uzair@unimap.edu.my

Abstract. Improper mold design or processing parameter setting could make a bad impact on the appearance of molded part. It becomes more challenging if the ratio of the part size compared with its wall thickness is greater. Process parameters such as mold and melt temperature, injection temperature including the cavity layout directly affect product quality and cost. It is a complex and difficult task to improve these multi parameters. The objective of this research is to determine optimum settings for processing parameters for a thin walled product by using Response Surface Methodology. Melting temperature, mold temperature, injection pressure and cavity layout are selected as processing parameters and Polyurethane material is selected for this research. Volumetric shrinkage and warpage are selected as the main quality criteria to be controlled respected with the product design specifications. As the result, optimum process parameter settings were mold temperature of 29.89°C, melting temperature of 220°C, and 181.30MPa injection pressure with ‘H’ branching cavity layout. With small differences error value between solution and simulation, 0.31% for volumetric shrinkage and 0.126% for warpage, the result was acceptable.

1. Introduction
Thin wall molding is a conventional form type for injection molding that focuses on mass-producing plastic parts that are thin wall and lightweight, main intension to minimise material cost as well as shorter cycle time without any structural compromise. In any manufacturing sector such as automotive parts, electronic devices, medical equipment, faster cycle time process durations, improved production efficiency will lead to bring the lower cost per part [1-5].

The definition of the thin wall is really about the size of the part compared with its wall thickness part. For a specific plastic part, as the wall thickness is diminished, the harder it is to fabricate utilizing the injection molding procedure process [6-9]. The size of a part puts a limit on how thin the wall thickness can be. For packaging compartments, thin wall implies wall thicknesses that are under 0.025 inch (0.62mm) with a stream length to wall thickness ratio greater than 200.

The injection molding process is utilized to deliver thinly walled plastic items for a wide assortment of use, a standout amongst the most well-known being plastic back cover smartphones. The manufacturing of back cover smartphone such as mold design, mold making and process parameters, every one of which will influence the last appearance of the plastic product [10]. Furthermore, injection molding design for a back cover smartphone should completely consider the structure and gathering of the product for injection molded parts. In the meantime, it is additionally important to consider the...
demoulding of the back cover smartphone for injection molding products and the arrangement of water channels and gates. At the same time, it can reduce the warpage and shrinkage effect of the back cover smartphone when using the injection molding process [11].

In order to get the best quality of the plastic product, this product must go through the number of simulation studies and process decision making before the actual fabrication processes begin [12-17]. Simulation based optimization is the most effective way to study the mold flow of thin wall plastic part before the actual fabrication processes begin [18-21]. Improper mold design or parameter setting for processing could affect the moulded part quality appearance especially a complex and thin wall product [22-24]. In any product development, determining the product’s optimal processing parameter, it can not only produce a high-quality product but also help eliminate the defects in the product [25-31].

2. Experimental

2.1. Experimental setup: 3-Dimensional model development

3D modeling of the back cover smartphone is done by using CAD software as shown in Figure 1 and Table 1 shows the details of the geometry and specification of the body part of the back cover smartphone.

![Figure 1. Isometric view of 3D back cover smartphone](image)

| Fixed parameter | Dimension (unit: mm) |
|-----------------|----------------------|
| Width           | 71.12                |
| Length          | 142.64               |
| Thickness       | 9.85                 |

2.2. Modelling Simulation

An injection molding simulation software is used to simulate the plastic injection flow in the mold. Figure 2 displays the model’s suggested gate position for the back cover smartphone. The position of the suggested gate is at N6459. The surface finish properties and appearance are determined by the position of the window.

![Figure 2. Injection location of the back cover smartphone](image)

2.3. Modelling Simulation

The selected responses in this study are warpage (Y₁) and volumetric shrinkage (Y₂) since these two responses are the most defects occurred in thin wall part. 60 simulations with different combinations of factors value generated by Design Expert software are based on the parameter design level shown in Table 2. Cavity layout is studied as a categorical factor in which herringbone (H), circular (C) and ‘H’ Branching (HB) layout are selected as the layout. Figure 3 displayed the type of cavity layout.
### Table 2. Levels of parameter design.

| No | Factor          | Units | Level | Type of factor |
|----|-----------------|-------|-------|----------------|
|    | Mold temperature| °C    | 20    | 30 | 40 | Numeric |
| A  | Melting temperature | °C | 220  | 230 | 240 | Numeric |
| B  | Injection pressure | MPa | 170  | 180 | 190 | Numeric |
| C  | Cavity layout   | -     | Herringbone | Circular | “H” branching | Categorical |

### Figure 3. Cavity layout: Herringbone, Circular, ‘H’ branching.

3. **Results and Discussions**

Simulation runs are conducted using Injection mold software and the results are obtained for responses of warpage and volumetric shrinkage as shown in Table 3. Warpage needs to be considered with the lower value because the higher value of the warpage means higher probabilities that product exposed to defect and affect the quality of the product [32-35]. The volumetric shrinkage percentage is considered with a minimum level to ensure the back cover smartphone become a good product. From results, the maximum values of the warpage observed during the simulation run 1 at 1.179mm while the minimum value of 0.889mm recorded for simulation run 21. The maximum value of shrinkage is run 5 at 12.49% and the minimum value is run 30 with 9.656%. Next, the value of volumetric shrinkage for minimum and maximum, the minimum is 8.903% in ‘H’ branching layout, but for maximum value is 12.49% in a circular layout.

3.1. **Regression model and ANOVA**

The regression model is the continuity of (ANOVA) test where it summarizes the accuracy of analysis and determines reasonable agreement for the model to be used to navigate further design space. Warpage and shrinkage were figured out by F-test of variance (ANOVA). Model F-value for both responses shown implies a significant study of 20.23 for the warpage and 802.38 for shrinkage. The “Pred R-Squared” for the warpage is 0.999793 is in reasonable agreement with the “Adj R-squared” of 0.999831. The “Pred R-Squared” for shrinkage is 0.999994 is in reasonable agreement with the “Adj R-Squared” of 0.999995. Next, through this analysis process, the equations were generated through the ANOVA analysis process as to calculate the predicted warpage and shrinkage responses value. The complete analytical comparison between simulation and model predicted for both responses are displayed in table 3.
Table 3. Analytical comparison between simulation and model predicted.

| Run | Factor          | Response (%) | A | B | C | D | Y1  | Y2  | Y1  | Y2  |
|-----|----------------|--------------|---|---|---|---|-----|-----|-----|-----|
| 1   | 20 240 190 Circular | 1.179 12.49 | 1.17855 | 12.4925 |
| 2   | 40 240 170 “H” branching | 1.106 10.42 | 1.1048 | 10.4172 |
| 3   | 40 240 170 Herringbone | 0.9567 11.81 | 0.95835 | 11.81 |
| 4   | 30 230 180 Circular | 1.154 11.71 | 1.15445 | 11.7075 |
| 5   | 40 240 170 Circular | 1.179 12.49 | 1.17855 | 12.4925 |
| 6   | 20 240 190 Herringbone | 0.9567 11.81 | 0.95835 | 11.81 |
| 7   | 30 230 170 “H” branching | 1.029 9.656 | 1.0302 | 9.65875 |
| 8   | 20 240 190 “H” branching | 1.106 10.42 | 1.1048 | 10.4172 |
| 9   | 40 220 190 Circular | 1.125 10.92 | 1.12455 | 10.9225 |
| 10  | 20 220 190 Circular | 1.125 10.92 | 1.12455 | 10.9225 |
| 11  | 40 230 180 Herringbone | 0.929 10.96 | 0.92735 | 10.96 |
| 12  | 40 230 180 Circular | 1.154 11.71 | 1.15445 | 11.7075 |
| 13  | 20 230 180 Circular | 1.154 11.71 | 1.15445 | 11.7075 |
| 14  | 20 240 170 Circular | 1.179 12.49 | 1.17855 | 12.4925 |
| 15  | 40 230 180 “H” branching | 1.029 9.656 | 1.0302 | 9.65875 |
| 16  | 30 230 180 Herringbone | 0.929 10.96 | 0.92735 | 10.96 |
| 17  | 40 220 170 Circular | 1.125 10.92 | 1.12455 | 10.9225 |
| 18  | 30 230 180 Circular | 1.154 11.71 | 1.15445 | 11.7075 |
| 19  | 30 230 190 Herringbone | 0.929 10.96 | 0.92735 | 10.96 |
| 20  | 20 240 170 Herringbone | 0.9567 11.81 | 0.95835 | 11.81 |
| 21  | 40 220 170 Herringbone | 0.8889 10.11 | 0.89055 | 10.11 |
| 22  | 30 230 190 “H” branching | 1.029 9.656 | 1.0302 | 9.65875 |
| 23  | 30 230 180 Herringbone | 0.929 10.96 | 0.92735 | 10.96 |
| 24  | 40 240 190 Herringbone | 0.9567 11.81 | 0.95835 | 11.81 |
| 25  | 30 230 180 Circular | 1.154 11.71 | 1.15445 | 11.7075 |
| 26  | 30 220 180 “H” branching | 0.951 8.903 | 0.9498 | 8.90025 |
| 27  | 20 230 180 “H” branching | 1.029 9.656 | 1.0302 | 9.65875 |
| 28  | 20 220 170 Herringbone | 0.8889 10.11 | 0.89055 | 10.11 |
| 29  | 30 230 180 Herringbone | 0.929 10.96 | 0.92735 | 10.96 |
| 30  | 30 230 180 Circular | 1.154 11.71 | 1.15445 | 11.7075 |
| 31  | 30 220 180 Herringbone | 0.8889 10.11 | 0.89055 | 10.11 |
| 32  | 30 230 180 “H” branching | 0.929 10.96 | 0.92735 | 10.96 |
| 33  | 30 230 180 “H” branching | 0.929 10.96 | 0.92735 | 10.96 |
| 34  | 30 230 180 Circula | 1.154 11.71 | 1.15445 | 11.7075 |
| 35  | 30 220 180 “H” branching | 0.951 8.903 | 0.9498 | 8.90025 |
| 36  | 30 230 180 Herringbone | 0.929 10.96 | 0.92735 | 10.96 |
| 37  | 30 230 180 Herringbone | 0.929 10.96 | 0.92735 | 10.96 |
| 38  | 40 240 190 Circular | 1.179 12.49 | 1.17855 | 12.4925 |
| 39  | 30 220 180 Circular | 1.125 10.92 | 1.12455 | 10.9225 |
| 40  | 40 230 180 “H” branching | 1.029 9.656 | 1.0302 | 9.65875 |
| 41  | 40 240 190 “H” branching | 1.106 10.42 | 1.1048 | 10.4172 |
| 42  | 20 220 170 “H” branching | 0.951 8.903 | 0.9498 | 8.90025 |
| 43  | 30 230 190 Circular | 1.154 11.71 | 1.15445 | 11.7075 |
| 44  | 30 230 180 Circular | 1.154 11.71 | 1.15445 | 11.7075 |
| 45  | 30 230 170 Herringbone | 0.929 10.96 | 0.92735 | 10.96 |
| 46  | 20 220 170 Circular | 1.125 10.92 | 1.12455 | 10.9225 |
| 47  | 20 220 190 Herringbone | 0.8889 10.11 | 0.89055 | 10.11 |
| 48  | 40 220 170 “H” branching | 0.951 8.903 | 0.9498 | 8.90025 |
| 49  | 30 230 180 Circular | 1.154 11.71 | 1.15445 | 11.7075 |
| 50  | 20 220 190 “H” branching | 0.951 8.903 | 0.9498 | 8.90025 |
Table 3. Analytical comparison between simulation and model predicted (Continued…).

| Run | Factor             | Response (%) | Simulation | Predicted |
|-----|--------------------|--------------|------------|-----------|
|     |                    | A  | B  | C  | D    | Y₁ | Y₂ | Y₁ | Y₂ |
| 51  | 30  | 240 | 180 | Herringbone |   0.9567 | 11.81 | 0.95835 | 11.81 |
| 52  | 20  | 240 | 170 | “H” branching | 1.106  | 10.42 | 1.1048 | 10.4172 |
| 53  | 40  | 220 | 190 | “H” branching | 0.951  | 8.903 | 0.9498 | 8.90025 |
| 54  | 30  | 230 | 180 | “H” branching | 1.029  | 9.656 | 1.0302 | 9.65875 |
| 55  | 30  | 230 | 180 | “H” branching | 1.029  | 9.656 | 1.0302 | 9.65875 |
| 56  | 30  | 230 | 180 | “H” branching | 1.029  | 9.656 | 1.0302 | 9.65875 |
| 57  | 30  | 230 | 170 | Circular     | 1.154  | 11.71 | 1.15445 | 11.7075 |
| 58  | 30  | 230 | 180 | “H” branching | 1.029  | 9.656 | 1.0302 | 9.65875 |
| 59  | 30  | 230 | 180 | Herringbone  | 0.929  | 10.96 | 0.92735 | 10.96   |
| 60  | 30  | 240 | 180 | “H” branching | 1.106  | 10.42 | 1.1048 | 10.4172 |

3.2. Effect of factors on the response

3D surface response results demonstrated by Design expert software to determine the interaction between mold temperature, melting temperature, injection pressure and cavity layout with respect to warpage and shrinkage as shown in Figures 4 and 5. The minimum result for warpage was while the mold temperature are 40°C and the values of melting temperature is 220°C for three different cavity layout. The minimum result for shrinkage was while the mold temperature at 20°C and when the melting temperature is 220°C for three different cavity layouts.

Figure 4. Warpage 3D surface graphs various for cavity layout (Herringbone, circular and ‘H’ branching)
3.3. Optimization of process parameters
To reach a minimum value of warpage and volumetric shrinkage, the parameter values are directly recommended by Design Expert software. Optimum process parameter settings were mold temperature (29.89°C), melting temperature (220°C), and injection pressure (181.30MPa) with ‘H’ branching cavity layout.

3.4. Validation of results
This validation was carried out by running a simulation with an optimum value of mold temperature, melting temperature, injection pressure with ‘H’ branching cavity layout as shown in Figures 6 and 7. From the result in Table 4, the maximum value of warpage is 0.9510mm, and the minimum value is 0.1815mm. For volumetric shrinkage, the maximum value is 8.903%, and the minimum value is 1.305%. This optimization is considered succeed since the percentage difference for both investigated responses was in an acceptable range.

\[
\text{Percentage different} = \frac{|\text{Numerical value} - \text{Simulation value}|}{\frac{1}{2} (\text{Numerical values} + \text{Simulation values})^2} \times 100\% \quad (1)
\]

**Table 4.** Comparison of design parameters between the initial value and optimum value.

| Response, Y       | Unit | Minimum value from RSM | Approximate value from software simulation | Percentage difference (%) |
|-------------------|------|------------------------|-------------------------------------------|---------------------------|
| Warpage           | mm   | 0.9498                 | 0.9510                                    | 0.126                     |
| Volumetric shrinkage | %   | 8.90025                | 8.903                                     | 0.31                      |
4. Conclusions

As a conclusion, this study has been performed with simulations by injection mold software and Response Surface Methodology as a Design of Experiment tool for optimizing the injection mold parameter of mold temperature (A), melting temperature (B), injection pressure (C) and cavity layout (D) with respect to responses of warpage $Y_1$ and shrinkage $Y_2$. This study found that the best parameters for minimum warpage and shrinkage is in ‘H’ branching cavity layout with mold temperature value at 20°C, melting temperature at 220°C and 190MPa injection pressure. For result validation, from simulation with these optimised parameters value, warpage and volumetric shrinkage were determined as 0.8889mm and 8.903% respectively in simulation software. From this analysis, it can be seen that the parameter of mold temperature, melting temperature, injection pressure and various types of cavity layout played as key factors that will affect plastic product quality especially in criteria of warpage and shrinkage.

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