Simulation-based optimization of plastic injection molding parameters for mini centrifugal pump body using response surface methodology

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Abstract. Control parameters of the injection molding and fabrication process are essential to the success of any micro-molding product fabrication. The goal of the study is to simulate and optimise the parameter for the plastic mini micro centrifugal pump body by using Response Surface Methodology. The material for this micro part is Polyphenylene Sulphide (PPS). This study is also investigating the impact of design parameters and processing parameters on the quality of a plastic moulded part to obtain optimal response and meets the requirement specification. The control factors chosen for this study are melting temperature, cooling time and injection pressure. Based on the complex shape of the body part of mini micro pump, volumetric shrinkage and warpage are selected as the essential quality that needs to be controlled. The selected processing parameter are melting temperature, cooling time and injection pressure. As a result, the optimum values suggested by the software are melt temperature of 315.98°C, cooling time of 362s and injection pressure of 62MPa. With small differences error value between solution and simulation, 0.27% for volumetric shrinkage and 0.19% for warpage, the result was acceptable.

1. Introduction
The trend in recent years across various industries has been all about miniaturization. It includes the manufacturing of micromechanical parts, medical, optical, and electronic products and devices [1-5]. The increasing trend in many industries of micro parts, downsizing and nanotechnology are expected to boost the market for micro injection molding technology, and as a result, everything related to it in the supply chain has adjusted to accommodate the new, compact size [6-9]. Decreased reagent amounts and shorter response time in miniaturization also reduced cost and can be coordinated with other miniaturized devices [10-12]. Conversely, increasing demand on micro parts has posed a great challenge to manufacturing engineers, product design engineers including mold designers.

Micropumps are devices that can control and manipulate small fluid volumes. The dimension of a micropump is in the scope of a couple of centimeters or micrometers. They were designed in small sizes to perform the critical task of transporting a small number of fluids with high accuracy. Micropumps are of extraordinary interest in microfluidics as a result of its size, reduction of weight and precision to control volumes [13,14]. Different applications of micro pump include drug delivery, hazardous fluid handling, heating and cooling in the electronic industry.
Microinjection molding is a practice of injection molding parts at a microscopic scale. However, at such a tiny scale, without appropriate and optimise injection molding process parameter settings, the product may cause problems in the injection molding fabrication process [15]. The right decision making is crucial in any product development especially in parameter design of manufacturing and fabrication stage [16-20]. Studies on the significant factors that influenced micro molding quality had been conducted by many researches, however simulation-based optimization studies on micro molding are still lacking.

Simulation-based optimization is the most effective way to study the strength of a mini micro centrifugal pump body before the actual fabrication processes begin and it applied to any product development [21-25]. The injection molding parameters are considered in this project to determine the most significant factor and accurate molding process parameter setting [26,27].

2. Experimental setup

3D geometry modeling design for the part of mini micro centrifugal pump body design was drawn by using Autodesk Solidwork 2015 as shown in Figure 1. Figure 2 shows the recommended gate location by Autodesk Moldflow Insight. Response Surface Methodology method was used to determine the most optimized parameters to control the responses of shrinkage and warpage.

![Figure 1. Design and dimension of the mini micro centrifugal pump body.](image1)

![Figure 2. Gate Location.](image2)

2.1 Design of experiment

Design Expert was used to analyse data. The experimental design selected for this response surfaces measured were shrinkage and warpage. A total of 20 runs were designed for the experiment as shown in Table 1.
Table 1. Design of experiment.

| Column Factor | Level 1 | Level 2 | Level 3 |
|---------------|---------|---------|---------|
| A Melting Temperature (°C) | 300 | 317 | 334 |
| B Cooling Time (s) | 145 | 202 | 342 |
| C Injection Pressure (MPa) | 42 | 52 | 62 |

3. Result and discussion

The simulation was conducted under the different parameters of melting temperature, cooling time and injection pressure in order to find factors that will affect the volumetric shrinkage and warpage. The numerical run that generates from Design Expert software was totally 20 times with different value orders of processing parameters. Table 2 shows the result of central composite design in actual value.

Table 2. Predicted value and percentage error.

| Run | A | B | C | Volumetric shrinkage | Predicted shrinkage | % error shrinkage | Warpage | Predicted warpage | % error warpage |
|-----|---|---|---|----------------------|---------------------|-------------------|---------|------------------|----------------|
| 1   | -1| -1| -1| 11.92                | 11.36               | 4.930             | 0.495   | 0.494            | 0.083          |
| 2   | 1 | 1 | 1 | 12.4                 | 12.3                | 0.813             | 0.468   | 0.468            | 0.049          |
| 3   | 0 | 0 | -1| 10.89                | 11.83               | 7.946             | 0.480   | 0.480            | 0.000          |
| 4   | -1| 0 | 0 | 11.16                | 11.36               | 1.761             | 0.493   | 0.494            | 0.122          |
| 5   | 0 | 1 | 0 | 11.81                | 11.83               | 0.169             | 0.480   | 0.479            | 0.203          |
| 6   | 0 | 0 | 0 | 11.82                | 11.83               | 0.085             | 0.480   | 0.480            | 0.027          |
| 7   | -1| 1 | -1| 11.93                | 11.36               | 5.018             | 0.494   | 0.494            | 0.010          |
| 8   | 1 | 0 | 0 | 12.4                 | 12.3                | 0.813             | 0.471   | 0.471            | 0.016          |
| 9   | 1 | 1 | -1| 12.4                 | 12.3                | 0.813             | 0.468   | 0.468            | 0.036          |
| 10  | 0 | 0 | 0 | 11.82                | 11.83               | 0.085             | 0.480   | 0.480            | 0.027          |
| 11  | 0 | -1| 0 | 11.82                | 11.83               | 0.085             | 0.480   | 0.480            | 0.089          |
| 12  | 0 | 0 | 0 | 11.82                | 11.83               | 0.085             | 0.480   | 0.480            | 0.027          |
| 13  | 0 | 0 | 1 | 11.82                | 11.83               | 0.085             | 0.480   | 0.480            | 0.050          |
| 14  | -1| 1 | 1 | 11.15                | 11.36               | 1.849             | 0.492   | 0.493            | 0.043          |
| 15  | 0 | 0 | 0 | 11.82                | 11.83               | 0.085             | 0.480   | 0.480            | 0.027          |
| 16  | 0 | 0 | 0 | 11.82                | 11.83               | 0.085             | 0.480   | 0.480            | 0.027          |
| 17  | 1 | -1| -1| 12.41                | 12.3                | 0.894             | 0.472   | 0.472            | 0.057          |
| 18  | 0 | 0 | 0 | 11.82                | 11.83               | 0.085             | 0.480   | 0.480            | 0.027          |
| 19  | -1| -1| 1 | 11.16                | 11.36               | 1.761             | 0.493   | 0.493            | 0.091          |
| 20  | 1 | -1| 1 | 12.41                | 12.3                | 0.894             | 0.472   | 0.472            | 0.045          |

3.1 Final equation in term of coded factor

The formula of shrinkage and warpage were generated by expert design software to calculate the predicted result for the warpage and shrinkage as shown in Table 2. The equation given was in terms of coded factors than we can change in display option from actual value to a code value. In the formula, A stands for melt temperature, B for cooling time and C for injection pressure.

Shrinkage= 11.83 + 0.47A

Warpage=0.479479 – 0.01176A – 0.00095B – 0.00037C + 0.002261A² – 0.00073AB + 0.0004AC

The accurateness of the simulation modeling and its method is important for reliable and realistic predictions in whatever kind of simulation analysis. From the result shown in Table 2, the average percentage of error was 2% and we can conclude the experimented value and predicted result was close and acceptable.
3.2 Validation of simulation results
Table 3 shows the suggested value for optimization by Design Expert Software. The optimization is achieved at melting temperature (315.98°C), cooling time (362s) and injection pressure (62MPa). The optimum values of each independent variable were successfully achieved by using RSM. The suggested value of parameters was validated through Autodesk Moldflow Simulation once again as shown in Figure 3 and Figure 4. With 0.254 percentage error for volumetric shrinkage and 0.187 for warpage, the results are acceptable.

| Table 3. Suggested value for optimization by Design Expert Software. |
|---------------------------------------------------------------|
| Melting Temperature | Cooling Time | Injection Pressure | Volumetric Shrinkage | Warpage |
| Optimum            | 315.98       | 362.00            | 62.00                | 11.80    | 0.4789 |
| Simulation         | -            | -                 | -                    | 11.77    | 0.4798 |
| Error (%)          | -            | -                 | -                    | 0.254    | 0.187  |

**Figure 3.** Result for volumetric shrinkage.

**Figure 4.** Result for warpage.

4. Conclusion
In this study, the simulation-based optimization of micropump was generated by using Response Surface Methodology. Generally, three significant factors were used to minimize the volumetric shrinkage and warpage which are melting temperature, cooling time and injection pressure. By using Design Expert software, the optimum value was suggested for melting temperature (315.98°C), cooling time (362s) and injection pressure (62MPa). Based on the suggested value, the optimum value of volumetric shrinkage and warpage were determined 11.8017 and 0.478892 in simulation Moldflow Software. The discrepancy between model responses and simulation results was in the range of 0.19%-0.27%. This implies that reliable prediction can be achieved through the suggested model response. It is significant to optimise parameters setting for micro-molding in order to fabricate a high accuracy complex micro part.

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