OPTIMIZATION OF PROCESS PARAMETERS OF PLASTIC INJECTION MOLDING FOR POLYPROPYLENE TO ENHANCE PRODUCTIVITY AND REDUCE TIME FOR DEVELOPMENT

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ABSTRACT

The injection molding process itself is a complex mix of time, temperature and pressure variables with a multitude of manufacturing defects that can occur without the right combination of processing parameters and design components. In this analysis input processing parameters are melt temperature (MT), Injection pressure(IP), holding pressure(HP) and cooling time(Cool Time) and responses considered for investigation of plastic injection molding process are cycle time and tensile strength. The material used for experimentation is polypropylene. The cycle time and tensile strength are obtained through series of experiments according to Taguchi’s L-9 Orthogonal Array to develop the equation. Experimental results are analyzed through Response Surface Method and the method is adopted to analyze the effect of each parameter on the cycle time and tensile strength to achieve minimum cycle time and maximum tensile strength. For optimization of input plastic injection molding processing parameters with responses RSM’s D-Optimal method.

Keywords: Plastic Injection Molding, DOE, RSM’s D-Optimal Method.

1. INTRODUCTION

Increasing the productivity and the quality of the plastic injected parts are the main challenges of plastic based industries, so there has been increased interest in the monitoring all aspects of the plastic injection molding parameters. Most production engineers have been using trial-and-error method to determine initial settings for a number of parameters, including melt temperature, injection pressure, injection velocity, injection time, packing pressure, packing time, cooling temperature, and cooling time which depend on the engineers’ experience and intuition to
determine initial process parameter settings. However, the trial-and-error process is costly and time consuming. Chang et al [1] studied the relationship between input process parameters for injection molded Dog-bone bar and outputs as weld line width and tensile impact using Taguchi method. He considered 7 input parameters such as melt and mold temperatures, injection and hold pressures, cooling and holding times, and back pressure and found that the melt and mold temperature, injection pressure, and holding time are the most effective, while hold pressure, holding time and back pressure are least important parameter. Loera et al [2] introduced a concept for deliberately varying the wall thicknesses of an injection molded part within recommended dimensional tolerance to reduce part warpage using Taguchi method. From the results, it is seen that varying wall thicknesses exhibited better warpage characteristics compared to the constant wall thicknesses. Instead of PIM, rotational molding (RM) is one of the most important polymer processing techniques for producing hollow plastic part. However, part warpage caused by inappropriate mould design and processing conditions is the problem that confounds the overall success of this technique. Yanwei Huyong [3] applied Taguchi method to systematically investigate the effects of processing parameters on the shrinkage behavior (along and across the flow directions) of three plastic materials. The results from the research shown that the mould and melt temperature, along with holding pressure and holding time, are the most significant factors to the shrinkage behavior of the three materials, although their impact is different for each material. Shuaib et al [4] studied the factors that contribute to warpage for a thin shallow injection-molded part. The process is performed by experimental method by Taguchi and ANOVA techniques are employed. The factors that been taking into considerations includes the mold temperature, melt temperature, filling time, packing pressure and packing time. The result shows that by S/N response and percentage contribution in ANOVA, packing time has been identified to be the most significant factors on affecting the warpage on thin shallow part. Longzhi et al [5] inestigated to avoid the surface sink marks on the automobile dashboard decorative covers, the combined effects of multi-molding process parameters are analyzed by the combination of orthogonal experiments and Mold flow simulation tests. By this method, it can gain the experiment data which can reflect the overall situation using fewer number of simulation test. Furthermore, the effects degree of different molding process parameters for surface sink marks are investigated, and the reasonable gate location and optimized parameter combination is obtained. It can solve the unreasonable appearance of process parameter settings. The mold design can fasten the mold developing schedule, thus shorten the cycle of product development, and improve the quality of products and the competitive ability of enterprise. Wen-ChinChen et al [6] in this research Taguchi method, back-propagation neural networks (BPNN), and Genetic algorithms (GA) are applied to the problem of process parameter settings for Multiple-Input Single-Output (MISO) Plastic injection molding. Taguchi method is adopted to arrange the number of experimental runs. Injection time, velocity pressure switch position, packing pressure, and injection velocity are engaged as process control parameters, and product weight as the target quality. Then, BPNN and GA are applied for searching the final optimal parameter settings.

2. EXPERIMENTAL WORK

For plastic injection molding thermoplastics are used. The material used for this experimentation is polypropylene and L&T Demage plastic injection molding machine 40T to 250T capacity (shot capacity-50gm to 1000gm) is used while conducting experiments. We have selected 6 different parts which are of polypropylene material and divided them into two categories (large and small) and three parts in each. The cycle time and tensile strength are obtained through series of experiment according to Taguchi’s L-9 Orthogonal Array. The process parameters used and their levels are presented in table 1 and table 2.
Table 1: Factors and operating levels for large category components

<table>
<thead>
<tr>
<th>SR. NO.</th>
<th>PART NAME / FACTORS</th>
<th>MT (°c)</th>
<th>IP(MPa)</th>
<th>HP(MPa)</th>
<th>COOL TIME(Sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Part Size L=125mm* B=55mm* H=15mm</td>
<td>222</td>
<td>81</td>
<td>55</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Thickness MIN=1mm; MAX=5mm</td>
<td>225</td>
<td>84</td>
<td>52</td>
<td>22</td>
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<tr>
<td></td>
<td></td>
<td>228</td>
<td>85</td>
<td>56</td>
<td>23</td>
</tr>
<tr>
<td>2</td>
<td>Part Size L=100mm* B=50mm* H=10mm</td>
<td>217</td>
<td>71</td>
<td>50</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>Thickness MIN=1mm; MAX=2mm</td>
<td>219</td>
<td>76</td>
<td>48</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td></td>
<td>221</td>
<td>79</td>
<td>53</td>
<td>22</td>
</tr>
<tr>
<td>3</td>
<td>Part Size L=90mm* B=40mm* H=10mm</td>
<td>209</td>
<td>68</td>
<td>40</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>Thickness MIN=0.5mm; MAX=2mm</td>
<td>212</td>
<td>71</td>
<td>38</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>215</td>
<td>74</td>
<td>43</td>
<td>19</td>
</tr>
</tbody>
</table>

Table 2: Factors and operating levels for small category components

<table>
<thead>
<tr>
<th>SR. NO.</th>
<th>PART NAME / FACTORS</th>
<th>MT (°c)</th>
<th>IP(MPa)</th>
<th>HP(MPa)</th>
<th>COOL TIME(Sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Part Size L=70mm* B=30mm* H=15mm</td>
<td>202</td>
<td>61</td>
<td>36</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Thickness MIN=2mm; MAX=4mm</td>
<td>205</td>
<td>65</td>
<td>32</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td></td>
<td>208</td>
<td>67</td>
<td>38</td>
<td>17</td>
</tr>
<tr>
<td>5</td>
<td>Part Size L=65mm* B=20mm* H=20mm</td>
<td>198</td>
<td>55</td>
<td>27</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Thickness MIN=1mm; MAX=3mm</td>
<td>200</td>
<td>58</td>
<td>26</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>202</td>
<td>62</td>
<td>31</td>
<td>16</td>
</tr>
<tr>
<td>6</td>
<td>Part Size L=60mm* B=25mm* H=15mm</td>
<td>192</td>
<td>40</td>
<td>24</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Thickness MIN=1mm; MAX=3mm</td>
<td>196</td>
<td>45</td>
<td>26</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>199</td>
<td>48</td>
<td>30</td>
<td>16</td>
</tr>
</tbody>
</table>

Result through experimental work is recorded and experimental data obtained for cycle time and tensile strength is analyzed.

3 DATA ANALYSIS

3.1 Mathematical equations for size L=125mm*B=55mm* H=15mm

-The regression equation is for cycle time

Cycle Time = - 121 + 0.611 MT + 0.038 IP+ 0.011 HP+ 0.857 Cool Time

S = 0.614239 R-Sq = 95.28% R-Sq(adj) = 90.57%

The parameter $R^2$ describes the amount of variation observed in cycle time is explained by the input factors. $R^2$ is obtained for above equation is 95.28%, indicate that the model is able to predict the response with high accuracy. Adjusted $R^2$ is a modified $R^2$ that has been adjusted for the number of terms in the model. If unnecessary terms are included in the model, $R^2$ can be artificially high, but adjusted $R^2$ (90.57 % obtained for above equation) may get smaller. The standard deviation of errors in the modeling, $S=0.614239$ Comparing the p-value to a commonly used $\alpha$-level = 0.05, it
is found that if the p-value is less than or equal to \( \alpha \), it can be concluded that the effect is significant. This clearly indicates that the MT has greatest influence on cycle time, followed by cool time, HP and IP. The p-values for MT, IP, HP and Cool time are 0.002, 0.765, 1.000 and 0.006 respectively. It can be seen that the most influencing parameters to cycle time for polypropylene material is melt temperature and cooling time followed by injection pressure and holding pressure. The same conclusion is carried out for following equations

- The regression equation for tensile strength

\[
\text{Tensile Strength} = -137 + 0.611 \text{MT (°c)} + 0.247 \text{IP(MPa)} + 0.0244 \text{HP(MPa)} + 0.133 \text{Cool Time(sec)}
\]

\[
S = 0.424088 \quad R-Sq = 96.84\% \quad R-Sq(adj) = 93.67\%
\]

3.2 Mathematical Equations for Size L=100mm* B=50mm* H=10mm

- The regression equation for cycle time

\[
\text{Cycle Time} = -244 + 1.00 \text{MT} + 0.007 \text{IP} + 0.439 \text{HP} + 1.88 \text{Cool Time}
\]

\[
S = 1.41798 \quad R-Sq = 90.95\% \quad R-Sq(adj) = 81.90\%
\]
- The regression equation for tensile strength

Tensile Strength = -189 + 0.917 MT + 0.133 IP + 0.0193 HP + 0.133 Cool Time

S = 0.380516   R-Sq = 97.45%   R-Sq(adj) = 94.91%

Graph 3: Residual Plots for cycle time of size L=100mm* B=50mm* H=10mm

Graph 4: Residual Plots for tensile strength of size L=100mm* B=50mm* H=10mm

3.3 Mathematical Equations of Size L=90mm* B=40mm* H=10mm

- The regression equation for cycle time

Cycle Time = -135 + 0.556 MT - 0.111 IP + 0.053 HP + 3.00 Cool Time

S = 0.800219   R-Sq = 96.54%   R-Sq(adj) = 93.08%

- The regression equation for tensile strength

Tensile Strength = -122 + 0.611 MT + 0.183 IP + 0.0193 HP + 0.183 Cool Time

S = 0.369031   R-Sq = 97.60%   R-Sq(adj) = 95.21%
3.4 Mathematical Equations of Size L=70mm* B=30mm* H=15mm

- The regression equation for cycle time

\[ \text{Cycle Time} = -5.52 + 0.0556 \times MT + 0.152 \times IP + 0.0609 \times HP + 0.411 \times \text{Cool Time} \]

\[ S = 0.262398 \quad \text{R-Sq} = 92.25\% \quad \text{R-Sq(adj)} = 84.51\% \]

- The regression equation is

\[ \text{Tensile Strength} = -94.3 + 0.533 \times MT + 0.123 \times IP + 0.0280 \times HP + 0.011 \times \text{Cool Time} \]

\[ S = 0.492526 \quad \text{R-Sq} = 94.38\% \quad \text{R-Sq(adj)} = 88.76\% \]
Graph 7: Residual Plots for cycle time of Size L=70mm* B=30mm* H=15mm

Graph 8: Residual Plots for tensile strength of Size L=70mm* B=30mm* H=15mm

3.5 Mathematical Equations of Size L=65mm* B=20mm* H=20mm

- The regression equation for cycle time

Cycle Time = - 67.2 + 0.333 MT + 0.0979 IP - 0.145 HP+ 1.31 Cool Time

S = 0.432661  R-Sq = 95.19%  R-Sq(adj) = 90.37%

- The regression equation for tensile strength

Tensile Strength = - 93.7 + 0.567 MT + 0.0797 IP+ 0.0007 HP- 0.0499 Cool Time

S = 0.178819  R-Sq = 98.46%  R-Sq(adj) = 96.93%
Graph 9: Residual Plots for cycle time of Size L=65mm* B=20mm* H=20mm

Graph 10: Residual Plots for tensile strength of Size L=65mm* B=20mm* H=20mm

3.6 Mathematical Equations of Size L=60mm* B=25mm* H=15mm

- The regression equation is

Cycle Time = -23.8 + 0.189 MT + 0.0010 IP - 0.107 HP + 0.667 Cool Time

S = 0.102259   R-Sq = 99.70%   R-Sq(adj) = 99.40%

- The regression equation is

Tensile Strength = -15.0 + 0.185 MT + 0.0565 IP + 0.0048 HP + 0.0011 Cool Time

S = 0.0882733  R-Sq = 98.91%  R-Sq(adj) = 97.83%
4. RESULT AND DISCUSSIONS

To optimize processing parameters with result in the plastic injection process of polypropylene RSM's D-Optimal method is used for optimum result. By graph no 13 following observations are made.

**Melt Temperature (MT):** By increasing melt temperature responses like cycle time and tensile strength increases. Therefore optimal setting is in the middle of the range (222.1818) because goal is to minimize cycle time and maximize tensile strength. Vertical faint line in the second column of graph represents optimal setting of melt temperature.

**Injection Pressure (IP):** Increasing IP also increases both the responses like cycle time and tensile strength also, but effect on cycle time is minimum as compare to tensile strength. Therefore composite desirability decreases by increasing pulse on time. Hence optimal setting is in the lower of the range (81.9293) because goal is to maximize tensile strength and minimize cycle time. Vertical faint line in the third column of graph represents optimal setting of IP.

**Holding Pressure (HP):** Increasing holding pressure tensile strength and cycle time decreases, but goal is to increase tensile strength and decrease cycle time. Therefore composite desirability increases by increasing holding pressure. Hence optimal setting is in the higher of the range (56)
because goal is to minimize cycle time and maximize tensile strength. Vertical faint line in the fourth column of graph represents optimal setting of holding pressure.

**Cooling Time (Cool Time):** Increasing cooling time cycle time and tensile strength increases, but goal is to decrease cycle time. Therefore composite desirability decreases slightly by decreasing. Hence optimal setting is in the lower of the range (20) because goal is to maximize tensile strength and minimize cycle time. Vertical faint line in the fifth column of graph represents optimal setting of cool time.

By the similar way observations are made for graph no. 14 to graph no.18 of different size.

**Graph 13:** Optimization Plot for cycle time and tensile strength of size L=125mm*B=55mm*H=15mm

**Graph 14:** Optimization Plot for cycle time and tensile strength of size L=100mm* B=50mm*H=10mm

**Graph 15:** Optimization Plot for cycle time and tensile strength Size of component L=90mm* B=40mm* H=10mm
To overcome the problem of conflicting responses of single response optimization, multi response optimization was carried out using desirability function in conjunction with response surface methodology. Various multi-characteristic models have been developed. Goals and limits were established for each response in order to accurately determine their impact on overall desirability. A maximum or minimum level is provided for all response characteristics which are to be optimized. The ranges and goals of input parameters viz. melt temperature, injection pressure, holding pressure and cooling time and the response characteristics cycle time and tensile strength are given.

The goal of optimization is to find a good set of conditions that will meet all the goals. It is not necessary that the desirability value is 1.0 as the value is completely dependent on how closely
the lower and upper limits are set relative to the actual optimum. A set of 9 optimal solutions is derived along with one global solution for the specified design space constraints.

5. CONCLUSION

In present work, experimental investigation has been reported on plastic injection molding process of Polypropylene material part. Response surface methodology (RSM) has been utilized to investigate the influence of four important parameters of PIM – melt temperature, injection pressure, holding pressure and cooling time on two responses namely cycle time and tensile strength. Taguchi design was employed to conduct the experiments and to develop a correlation between the PIM parameters and each response. The analysis of experimental work is performed using MINITAB 16 statistical software. The important conclusions found that most significant factors for cycle time are melt temperature and cooling time least significant factors are injection pressure and holding pressure. For tensile strength most significant factors are melt temperature and injection pressure and least significant factors are holding pressure and cooling time. The influence of all factors has been identified and believed can be a key factor in helping mould designers in determining optimum process conditions injection moulding parameters to enhance productivity and reduce time for new product development.

Table 3: Optimal Setting with responses for large type component using RSM’s D-Optimal Method

<table>
<thead>
<tr>
<th>SR. NO.</th>
<th>PART NAME/ OPTIMIZE SETING PARAMETERS AND RESPONSE</th>
<th>MT (°c)</th>
<th>IP (MPa)</th>
<th>HP (MPa)</th>
<th>COOL TIME(Sec)</th>
<th>CYCLE TIME(Sec)</th>
<th>TENSILE STRENGTH (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Part Size L=125mm<em>B=55mm</em>H=15mm Thickness MIN=1mm; MAX=5mm</td>
<td>222.1</td>
<td>81.9</td>
<td>56</td>
<td>20</td>
<td>35.1285</td>
<td>23.0043</td>
</tr>
<tr>
<td>2</td>
<td>Part Size L=100mm* B=50mm* H=10mm Thickness MIN=1mm; MAX=2mm</td>
<td>220.8</td>
<td>79</td>
<td>48</td>
<td>19</td>
<td>33.8565</td>
<td>26.9982</td>
</tr>
<tr>
<td>3</td>
<td>Part Size L=90mm* B=40mm* H=10mm Thickness MIN=0.5mm;MAX=2mm</td>
<td>214.6</td>
<td>74</td>
<td>38</td>
<td>17</td>
<td>28.6752</td>
<td>26.7883</td>
</tr>
</tbody>
</table>

Table 4: Optimal Setting with responses for small type component using RSM’s D-Optimal Method

<table>
<thead>
<tr>
<th>SR. NO.</th>
<th>PART NAME/ OPTIMIZE SETING PARAMETERS AND RESPONSE</th>
<th>MT (°c)</th>
<th>IP (MPa)</th>
<th>HP (MPa)</th>
<th>COOL TIME(Sec)</th>
<th>CYCLE TIME(Sec)</th>
<th>TENSILE STRENGTH (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Part Size L=70mm* B=30mm* H=15mm Thickness MIN=2mm;MAX=4mm</td>
<td>208</td>
<td>61.06</td>
<td>32</td>
<td>14</td>
<td>23.0037</td>
<td>25.2309</td>
</tr>
<tr>
<td>5</td>
<td>Part Size L=65mm* B=20mm* H=20mm Thickness MIN=1mm;MAX=3mm</td>
<td>202</td>
<td>59.808</td>
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<td>14</td>
<td>19.8452</td>
<td>24.8696</td>
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<tr>
<td>6</td>
<td>Part Size L=60mm* B=25mm* H=15mm Thickness MIN=1mm;MAX=3mm</td>
<td>199</td>
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<td>30</td>
<td>12</td>
<td>18.6068</td>
<td>24.6274</td>
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REFERENCES


[5] “Optimization of Plastics Injection Molding Processing Parameters Based on the Minimization of Sink Marks” Zhao Longzhi1, Chen Binhui1, Li Jianyun, Zhang Shangbing IEEE 2010 PP 1-3


