Experimental Analysis and Optimization of Process Parameters of Plastic Injection Moulding for the Material Polypropylene

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Abstract— In present work, experimental analysis and optimization of process parameters of plastic injection moulding has been reported. Response surface methodology (RSM) has been utilized to investigate the influence of three important input parameters – plasticizing temperature, injection pressure and cooling time on two performance characteristics- Tensile Strength of material Polypropylene (PP). Centered central composite design was employed to conduct the experiments and to develop a correlation between the process parameters and performance characteristics. The analysis of experimental work is performed using MINITAB 16 statistical software. Response surface methodology (RSM) was applied for developing the mathematical models in the form of regression equation and to find optimized values of process parameters. The optimum set of process parameters obtained are cross validated by using ANOVA method. The influence of all factors has been identified which can play a key role in increasing Tensile Strength of PP. Surface plots and Contour plots have been plotted for studying combined effect of two factors while keeping other factor at their mid-values. From ANOVA it is clear that for Polypropylene to achieve maximum Tensile Strength injection pressure is the most significant factor followed by cooling time and plasticizing temperature followed by injection pressure and cooling time.

Key words: ANOVA, Polypropylene, Response Surface Methodology (RSM)

I. INTRODUCTION

Injection Moulding is an extensive global manufacturing process for making simple to intricate plastic, ceramic and metal parts. Injection Moulding converts wax, thermoplastics, thermo sets as well as powdered metals and magnesium into thousands of products. Injection Moulding is the most commonly used manufacturing process for the fabrication of plastic parts. A wide variety of products are manufactured using injection moulding, which vary greatly in their size, complexity, and application. The injection moulding process requires the use of an injection Moulding machine, raw plastic material, and a mould. Injection Moulding is a manufacturing process which is producing parts from both thermoplastic and thermosetting plastic materials. transformation of plastic pellets into a moulded part.

II. SYSTEM MODEL

An injection moulding machine produces components by injection moulding process. Most commonly used machines are hydraulically powered in-line screw machines, although electric machines are appearing and will be more dominant in the market in near future. The main units of a typical injection moulding machine are the clamping unit, the plasticizing unit, and the drive unit; they are shown in Figure 1. The clamping unit holds the mould. It is capable of closing, clamping, and opening the mould. Its main components are the fixed and moving plates, the tie bars and the mechanism for opening, closing and clamping. The injection unit or plasticizing unit melts the plastic and injects it into the mould. The drive unit provides power to the plasticizing unit and clamping unit. The clamping force of typical injection moulding machines range from 200 to 100,000 kN.

III. PREVIOUS WORK

B.KC, et.al Sisal-glass fiber hybrid biocomposite: Optimization of injection molding parameters using Taguchi method for reducing shrinkage, Science Direct, 2016, had applied the Taguchi method to optimize the injection moulding (IM) process parameters for sisal and glass fiber hybrid biocomposite. Injection pressure, melt temperature,
mold temperature, holding pressure, cooling time and holding time are the six parameters selected that influence flow and cross-flow shrinkage. Two hybrid biocomposites were used with different content of sisal(SF) and glass fiber(GF); SF20GF10 and SF10GF20.L18 orthogonal array with a mixed-level design and signal-to-noise ratio (S/N) of smaller-the-better was used for experimental design. For both hybrid biocomposites, optimal injection molding settings for minimizing the shrinkage are injection pressure 90 bar, melting temperature 210 °C, mold temperature 40 °C, cooling time 40s, hold time 6s and optimal holding pressure for SF20GF10 was 70 bar and for SF10GF20 was 50 bar. Based on ANOVA analysis, injection pressure had significant influence on both flow shrinkage and x-flow shrinkage of SF20GF10. For SF10GF20, no factors show significant impact on flow shrinkage; however injection pressure and mold temperature had significant impact on x-flow shrinkage.

M.I. Mat Kandara, et.al, Application of DoE for Parameters optimization of compression injection moulding for Flax reinforced bicomposites, Science Direct, 2016. widespread research on polymer composites that consist of natural fiber as reinforcement have been widely discussed. In this work, an attempt on optimizing the hot press forming process parameters using Response Surface Methodology (RSM) have been made to improve the mechanical properties of the woven flax/PLA composites. Three independent process variables, including moulding temperature, time and pressure were studied. Through the Box Behnken approach, a set of experiment runs based on various combination of compression moulding via Minitab 16 were established. As a results the optimum value for the variables of compression moulding technique parameters were 200°C, 3 min and 30 bar in order to yield 48.902 kJ/m² two impact strength. The investigation of this work dealt with the application of RSM using a Box Behnken design (BBD) to optimise the mechanical properties of woven flax/PLA. The ANOVA data showed that the variables are affected the impact strength significantly. The inter-actions of variables also have significant effects on impact strength. The optimal set of processing parameters for woven flax/PLA was found to be moulding temperature (200°C), moulding time (3 min) and moulding pressure (30 bar), to achieve the maximum impact strength of 48.902 kJ/m².

Amit Kumar, et.al, Time-Based Optimization of Injection Moulding Process Using Response Surface Methodology, 2015 This study has been made to optimize the process parameters during forming of PVC (L-bow) fitting by injection moulding machine using response surface methodology (RSM). Four input process parameters of injection moulding machine namely filling time, refill time (RFT), tonnage time (TT) and Ejector retraction time (ERT) is chosen as variables to determine the process performance in terms of cycle time (CT). The analysis of variance (ANOVA) is carried out to determine the effect of process parameter on process performance. The parameters filling time (23), refill time (36) tonnage time (0.68) and Ejector retraction time (1.36) are identified as the most significant optimal setting for Cycle time (CT). In this work, the application of response surface methodology (RSM) on PVC material on injection moulding machine are explained. In addition, a quadratic model is established for Cycle Time (CT) so as to examine the influence of process parameters on it. Following are the results to be found:

- From the ANOVA it is proved that with the help of quadratic mathematical model the prediction of Cycle Time (CT) with 94.21%. Confident interval.
- All the cutting parameters have significant effect but filling time(FT), tonnage time (TT), and Ejector retraction time (ERT) have the most significant effect with the contribution of 85.26%, 1.92% and 3.10% respectively in the total variability of model.

Anand K. Dwivedi, et.al, Practical application of Taguchi method for optimization of process parameters of injection molding machine for PP material, International Research journal of engineering and technology, 2015, instead of the old concept of trial and error method to determine the process parameters for injection molding aimed to analyze the recent research to determine optimal process parameters of injection molding. The optimization of injection molding process parameters for polypropylene (PP) material has been done using Taguchi methodology. This methodology provides the optimum value of process parameters with the help of orthogonal array by conducting very few experiments. Processing temperature, Injection pressure, Cooling time and Injection speed are the selected process parameters. The process parameters are optimized by considering Tensile strength as responding factor. The response table for S/N ratio gave the best set of combination for process parameters and highest value for each factor is selected. For Tensile strength of PP, processing temperature is found most effecting factor followed by injection speed, injection pressure and cooling time.

Michael Packianather, et.al, Micro injection moulding process parameter tuning, ScienceDirect, 2015 This paper focuses on tuning the micro injection moulding process parameters. In this study four process parameters namely, barrel temperature, mould temperature, holding pressure and injection speed were considered. In order to capture their behaviour a L16 Orthogonal Array with two levels for each parameter was employed to produce the design of a 15 mm x 20 mm x 1 mm microfluidic platform using Cyclic Olefin Copolymer (COC), a common polymer. The demoulding force was measured during the micro injection moulding process. The sixteen trials were repeated ten times to incorporate process variation, systematic and random noise in the experimental procedure. The results were analysed using Taguchi method to identify the influence of the process parameters upon the demoulding force and their sensitivity to noise. In addition, the results also indicated either the presence or absence of the two level interactions between these process parameters. This study has contributed to understanding the characteristics of these process parameters in terms of their main effects, interactions and sensitivity to noise and to tune them for their optimal performance. Design of experiment using Taguchi L16 Orthogonal Array has been conducted with four process parameters namely, mould temperature, barrel temperature, holding pressure, and injection speed in order to understand the effect of these parameters during the micro injection moulding process. The analysis was carried out using Minitab16. Two criteria for S/N were used. This study has shown that the most significant parameters are mould temperature and holding pressure. Different polymers will
be used in the future to study the effects of these process parameters upon different materials.

IV. PROPOSED METHODOLOGY
The Experimental Set-up (Injection moulding machine), work piece material, tensile and flexural sample specifications, process parameters (input and output) and measuring instruments.

A. Materials Used In the Process
The tensile specimens are made by using Polypropylene (PP).

B. Polypropylene
PP- Homopolymer 110MA is a natural coloured grade produced by Spheripol II Technology. The grade is high flow & high rigidity and excellent gloss. This grade contains antistatic agent that reduces static charge built up in products. Recommended Processing Temperature: 150 – 260°C

C. Input Parameters Plasticizing Temperature
It is the change in the thermal and mechanical properties of a given polymer which involves:
- Lowering of rigidity at room temperature;
- Increase of the elongation to break at room temperature;
- Increase of the toughness (impact strength) down to the lowest temperature of service ability.

D. Injection Pressure
Injection pressure is defined as the pressure on the face of the injection screw when melt material was injected into the mould. With an increase in injection pressure shrinkage decreases.

E. Cooling/Time
Cooling time is commonly defined as the time from the end of packing stage toward ejection. The criticality of cooling time in terms of shrinkage was confirmed also by considering techniques different from injection moulding.

F. Response Parameters
1) Tensile Strength
Tensile Strength determines the behaviour of materials under axial stretch loading. Data from test are used to determine elastic limit, elongation, modulus of elasticity, proportional limit, reduction in area, tensile strength, yield point, yield strength and other tensile properties. Methods for tensile tests of plastics are outlined in ASTM D-638.

2) Tensile Specimen
The tensile specimens are manufactured on the injection moulding machine. The dimensions of the tensile samples are ASTM D 638-2010 Dumbbell 127×12.7×3.2mm

V. SIMULATION/EXPERIMENTAL RESULTS
In this paper, the experimental results were obtained by conducting experiments based on DOE by Response surface methodology’s (RSM) Central composite design using Minitab 16 software.

<table>
<thead>
<tr>
<th>Plasticizing Temp</th>
<th>Injection Pressure</th>
<th>Cooling Time</th>
<th>Tensile Strength N/mm²</th>
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<td>185</td>
<td>38.1821</td>
<td>30</td>
<td>36.4681</td>
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<td>65</td>
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<tr>
<td>200</td>
<td>45</td>
<td>35</td>
<td>36.1281</td>
</tr>
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</table>

Table 1: Polypropylene input and output parameters values in RSM
A. Central Composite Design for Tensile Strength of Polypropylene

Fig. 4: Surface Plot of Tensile Strength vs Injection Pressure, Plasticizing Temperature, Cooling Time

Fig. 4: Contour Plot of Tensile Strength vs Injection Pressure, Plasticizing Temperature, Cooling Time

Fig. 5: Overlaid Contour Plot of Tensile Strength

Table 2: Estimated Regression Coefficients for Tensile Strength

<table>
<thead>
<tr>
<th>Term</th>
<th>Coef</th>
<th>SE Coef</th>
<th>T</th>
<th>P</th>
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<tr>
<td>Constant</td>
<td>27.7454</td>
<td>21.8707</td>
<td>1.269</td>
<td>0.279</td>
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<tr>
<td>Plasticizing Temp(A)</td>
<td>0.1084</td>
<td>0.1814</td>
<td>0.598</td>
<td>0.034</td>
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<td>Injection Pressure(B)</td>
<td>-0.643</td>
<td>0.2131</td>
<td>-3.018</td>
<td>0.013</td>
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<tr>
<td>Cooling Time(C)</td>
<td>1.1982</td>
<td>0.4449</td>
<td>2.693</td>
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</tr>
<tr>
<td>A*B</td>
<td>0.0004</td>
<td>0.0004</td>
<td>0.789</td>
<td>0.448</td>
</tr>
<tr>
<td>B*C</td>
<td>0.0041</td>
<td>0.001</td>
<td>4.187</td>
<td>0.002</td>
</tr>
</tbody>
</table>

S = 0.3786 R-Sq = 88.4%  R-Sq(adj) = 77.9%

Fig. 6: Residual Plots for Tensile Strength

Fig. 7: Response Optimiser for Tensile Strength

Global solution after response optimization
Plasticizing Temperature: 195.7699°C
Injection Pressure: 71.8150 bar
Cooling Time: 21.6190 sec
The maximum value of Tensile Strength is 37.0435N/mm²

VI. CONCLUSION

In present work, experimental analysis and optimization of process parameters of plastic injection moulding has been reported. Response surface methodology (RSM) has been utilized to investigate the influence of three important input parameters – plasticizing temperature, injection pressure and cooling time on two performance characteristics - Tensile Strength of materials Polypropylene (PP). Centered composite design was employed to conduct the experiments and to develop a correlation between the process parameters and performance characteristics. The analysis of experimental work is performed using MINITAB 16 statistical software. The important conclusions that can be drawn from the present research work are summarized as follows:-

Response surface methodology (RSM) was applied for developing the mathematical models in the form of regression equation.
The influence of all factors has been identified which can play a key role in increasing Tensile Strength of PP.
- Surface plots and Contour plots have been plotted for studying combined effect of two factors while keeping other factor at their least-values.
- The optimized value of input parameters was obtained to achieve maximum values of Tensile strength for the material PP.
- From ANOVA it is clear that:-

For Polypropylene to achieve maximum Tensile Strength injection pressure is the most significant factor followed by cooling time and plasticizing temperature.

VII. FUTURE SCOPES
Although investigation has been done for process parameters still there is scope for further improvement. The following suggestions may prove useful for future work:
1) Any other mechanical or electrical property of the material can be measured as a response parameter
2) Efforts can be taken to investigate the effects of process parameters on shrinkage and warpage of the materials.

REFERENCES