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Parametric Study for a Reciprocating Screw Blow Injection Molding Process Using Design of Experiments Tools

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Abstract

The quality of injection-molded products has been extremely important for customers, because quality is critical to satisfying customers' needs and retaining their loyalty. The factors affecting the quality of parts made by injection molding are numerous. They range from materials used, processes, workers, environment, or a combination of any of these. The injection is a critical operation in the blow injection molding process, therefore, the focus of the present study is to optimize process related factors of the injection operation and understand the effect of some factors and more importantly the interaction between the different factors on the quality of the final product. In the present study, the effect of three core factors was studied. The factors considered were: holding time, holding pressure, and flow. The results showed that the effect of flow and the interaction between flow and holding time were statistically significant and should be carefully considered.

Keywords:...

1. Introduction

Injection molding is the process of forming parts by placing pellets into one side of a cylinder through the Hopper, heating them inside heating chamber and through heating bands located along the screw, and extruding the molten material out to a closed mold in which the material fills and take the shape of a mold cavity as shown in Figure 1.

In the blow injection molding process, the factors affecting the quality of the final product are numerous, which resulted in difficulties in optimizing them. For example, process related variables could be: materials temperature, mold temperature, injection pressure, mold fill rate, clamping force on the mold, shot volume, viscosity of the material, and machine cycle time.

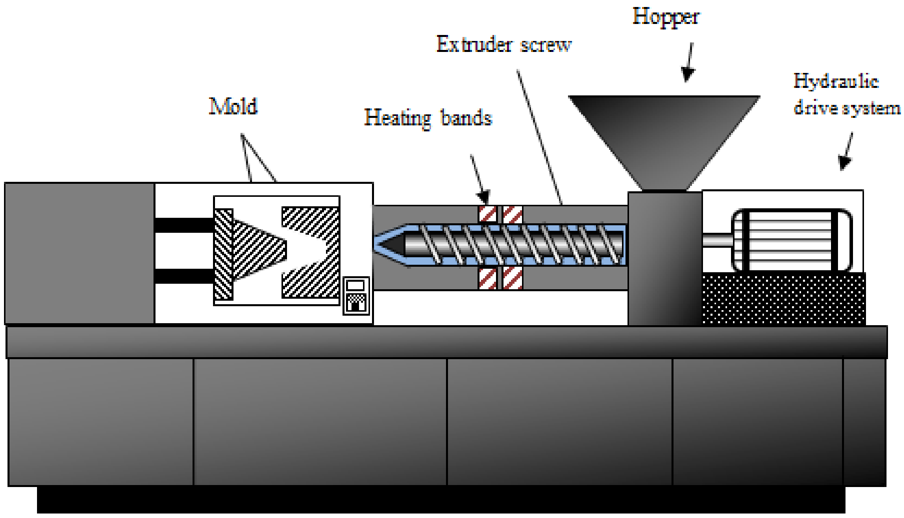

Figure 1. Sketch of the blow injection molding process

Many studies have been done to improve the injection molding process through improvement of materials, improving the process, or even the environmental conditions. For example, Demirel and Daver[1] have

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studied experimentally the perform reheat temperature carried out on a PET bottle produced by a two-stage ISBM machine. Quality of these bottles was measured in terms of top-load strength, burst pressure resistance, Environmental Stress Cracking Resistance (ESCR), and thermal stability. Others have introduced a methodology based on response surface to study the shrinkage and warpage in an injection molded part that has a thin shell element during the injection molding process, Ko-Ta and Fu-Ping[2]. Four factors were considered in their study: mold temperature, packing time, packing pressure, and cooling time. Kramschuster*et al.*[3] have studied the effects of processing conditions on the shrinkage and warpage behavior of a box shaped, polypropylene part using conventional and microcellular injection molding. Six factors were considered in their study: hold time, cooling time, injection speed, hold pressure, max barrel temperature, and chiller temp.

Garbacz and Palutkiewicz[4] have investigated the effect of the type and content of blowing agents in polymeric materials being processed on some physical and mechanical properties of the obtained parts. Salomeia*et al.*[5] have studied the effect of some processing parameters on the quality of the product produced in stretch blow molding process. Záboj, in his work [6], has discussed the effect of melt temperature, injection rate, and holding pressure on the wall thickness of a rectangular plate using polypropylene homopolymer and 40 % talc filled polypropylene material. Tan *et al.*[7] studied the effect of biaxial stretching on the mechanical properties of Polyethylene Terephthalate (PET). They have studied the effect of temperature, strain rates, and stretch ratios on the tensile modulus of the specimens cut from biaxial stretch sheets. Yan and Menary[8] have developed a finite element model to study the sequential stress strain behavior as a function of temperature and strain rate for PET used in stretch blow molding.

Yi-Cheng*et al.*[9] have studied the warpage of plastic fitting, simulation tools were used to study the effect of plastic melting temperature, mold temperature, injection time, packing pressure, packing time, and cooling time on the amount of warpage in the part considered. Artificial neural networks combined with genetic algorithm were used to come up with optimum process parameters that minimize warpage.

Ong *et al.*[10] have proposed a three-dimensional roughness model for filling polymer flow in microinjection molding to study the effect of surface roughness of microcavities on the final quality of the produced part. On the other hand, Zhang *et al.*[11] have also studied the effect of surface roughness on cavity filling in micro injection process for a limited range of injection rate. One the other hand, Menary*et al.*[12] have developed simulation models for the stretch blow molding process based on some experimental studies.

A lot of research has been conducted to evaluate the mechanical properties of either molded parts or the material used. For example, Bociaga and Palutkiewicz[13] have studied certain process parameters (mold temperature and blowing agent percentage) on selected properties of molded parts. The considered properties in their work were weight, mechanical properties, surface state - gloss and color. On the other hand, Manas*et al.*[14] have studied the influence of beta radiation on selected mechanical and thermal properties. Biglione*et al.*[15] have used finite element modeling to study the material behavior in process conditions in a single stage process.

Bordival*et al.*[16] studied the heat transfer problem between the mold and the polymer during the injection molding process. They have developed an experimental method evolution of the thermal contact resistance with time. Amran*et al.*[17] have conducted an optimization study on the size of gate, runner, sprue, in two plate family injection molding process for better quality of molded parts. Al-Refaie*et al.* [18] have used a Data Envelopment Analysis (DEA) method to Measure the Efficiencies of Blowing Machines.

In the present study, the effect of holding time, holding pressure, and flow on the quality of a hollow conical-shaped part was studied. Poypropylene was the material used in the present study; polypropylene has a specific gravity of approximately 0.9. It is capable of withstanding high temperatures. It can be extruded, injection and blow molded[19].

Methodology

For the design of the experiment tools used in the present study, three factors were considered: holding time, holding pressure, and flow. For each of these factors, three levels were considered: low, medium, and high, as shown in Table 1 below.

Table 1. Experiment factors and levels

Factor / Level	Holding time (sec)	Holding pressure (bar)	Flow (%)
Low	1	30	30
Medium	2	40	40
High	3	50	50

Minitab 17 software was used to build a full factorial design matrix, as shown in Table 2. Twenty seven randomized experimental runs have resulted. Experiments were randomized to minimize biased results which could result if the experiments were conducted in a certain sequence. For each experimental run, three parts were produced and the measurement conducted on each part was averaged. The thicknesses of the resulted parts at specified locations were measured, as shown in Table 2.

Result

A waviness effect could result in the molded parts at locations that are difficult to reach by the molten plastic; an example of such locations is the edges, as shown in Figure 2. Thickness measurements were carefully made at locations of uniform and even surfaces away from the edges of the part

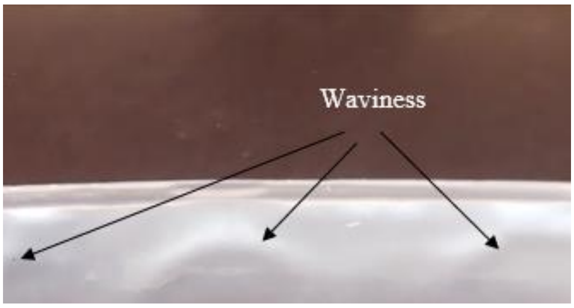

Figure 2. Waviness of plastic

The thicknesses measurements were conducted using dial indicator setup, shown in Figure 3. The setup consisted of a heavy base, connecting rods, and a dial indicator. The resolution of the dial indicator used was 0.01 mm.

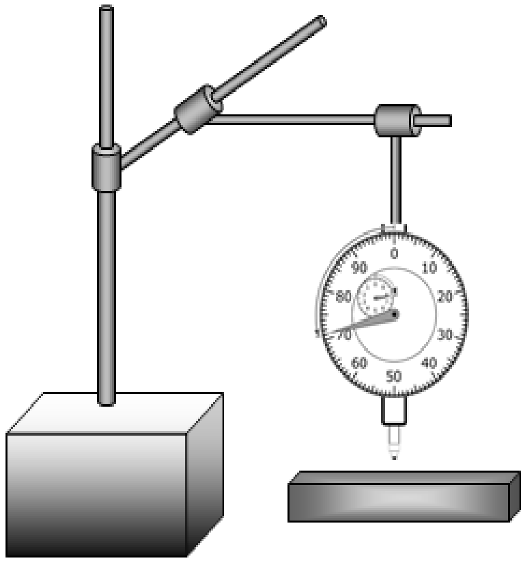

Figure 3. Experimental setup for thickness measurement

Table 2. Full factorial design matrix and thickness measurement

Run #	Time	Pressure (bar)	Flow (%)	Thickness (mm)	Run #	Time (sec)	Pressure (bar)	Flow (%)	Thickness (mm)
1	1	30	50	1.68	15	2	40	50	1.67
2	3	30	40	1.66	16	3	40	30	1.65
3	1	30	30	1.66	17	2	30	40	1.66
4	2	50	50	1.69	18	1	40	40	1.71
5	3	30	50	1.69	19	1	50	40	1.70
6	3	50	40	1.67	20	2	50	30	1.68
7	2	40	40	1.66	21	3	50	30	1.65
8	1	30	40	1.70	22	1	50	50	1.69
9	2	50	40	1.67	23	1	50	30	1.65
10	3	30	30	1.66	24	1	40	50	1.66
11	2	40	30	1.65	25	3	40	40	1.68
12	1	40	30	1.68	26	3	50	50	1.68
13	2	30	50	1.69	27	2	30	30	1.70
14	3	40	50	1.69					

Analysis of variance (ANOVA) [20] is a statistical tool used to detect differences in means (averages) between various levels of a factor. The equations governing the total sum of squares and the sum of squares of the factors and their interactions are listed below:

$$SST = \sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{c}\sum_{l=1}^{n} y_{ijkl}^2 - \frac{y_{....}^2}{abcn}, \quad SS_A = \sum_{i=1}^{a}\frac{y_{i...}^2}{bcn} - \frac{y_{....}^2}{abcn}, \quad SS_B = \sum_{j=1}^{b}\frac{y_{.j..}^2}{acn} - \frac{y_{....}^2}{abcn},$$

$$SS_C = \sum_{k=1}^{c}\frac{y_{..k.}^2}{abn} - \frac{y_{....}^2}{abcn}, \quad SS_{AB} = \sum_{i=1}^{a}\sum_{j=1}^{b}\frac{y_{ij..}^2}{cn} - \frac{y_{....}^2}{abcn} - SS_A - SS_B, SS_{AC} = \sum_{i=1}^{a}\sum_{k=1}^{c}\frac{y_{i.k.}^2}{bn} - \frac{y_{....}^2}{abcn} - SS_A - SS_C, SS_{BC} = \sum_{j=1}^{b}\sum_{k=1}^{c}\frac{y_{.jk.}^2}{an} - \frac{y_{....}^2}{abcn} - SS_B - SS_C$$

It can be noticed that the main effect of flow and the interaction between flow and holding time are significant based on a 95% confidence level with P-values 0.031, and 0.020, respectively, as shown in Table 3. The model has an R-sq value of 85.94%.

A residual plot was constructed as shown in Figure 4; it can be observed from the plot that the ordinary least squares assumptions are being met. For the residual analysis, a normal probability plot for residuals was also constructed, as shown in Figure 5. This plot is used to check if there is any measurement heteroscedasticity, it can be clearly seen that the model assumption of normally distributed errors is satisfied.

Table 3. ANOVA table

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	18	0.007111	0.000395	2.72	0.076
Linear	6	0.002311	0.000385	2.65	0.102
Time	2	0.000563	0.000281	1.94	0.206
Pressure	2	0.000141	0.000070	0.48	0.633
Flow	2	0.001607	0.000804	5.53	0.031
2-Way Interactions	12	0.004800	0.000400	2.75	0.079
Time*Pressure	4	0.000904	0.000226	1.55	0.276
Time*Flow	4	0.003170	0.000793	5.45	0.020
Pressure*Flow	4	0.000726	0.000181	1.25	0.365
Error	8	0.001163	0.000145		
Total	26	0.008274			

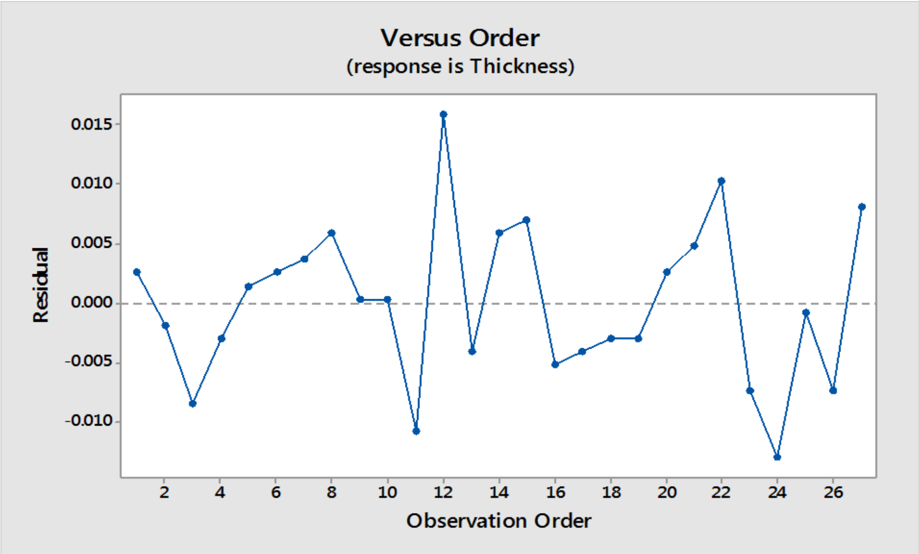

Figure 4. Residual plot

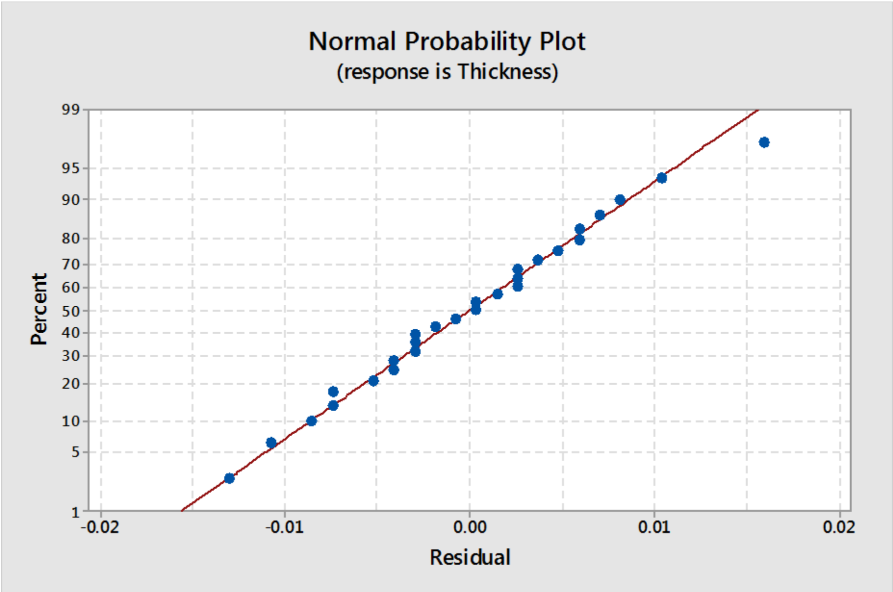

Figure 5. Normal Probability Plot

The ANOVA table shows that the main effect of flow is significant based on a 95% confidence level. Therefore, a main effect plot of the flow factor is shown in Figure 6. It can be clearly seen that the mean of the response is not the same across all factor levels, which means, different levels of the flow factor affect the response differently. It can also be noticed that the steeper the slope of the line, the greater the magnitude of the main effect.

Interaction plots were also constructed to test whether the relationship between one categorical factor and a continuous response depends on the value of the second categorical factor. When two factors interact, that means that changes in the response variable cannot be interpreted by independent effects of the two factors. Rather, the explanation will be more complicated in such a way that the effect of one factor depends on what has happened to the other factor.

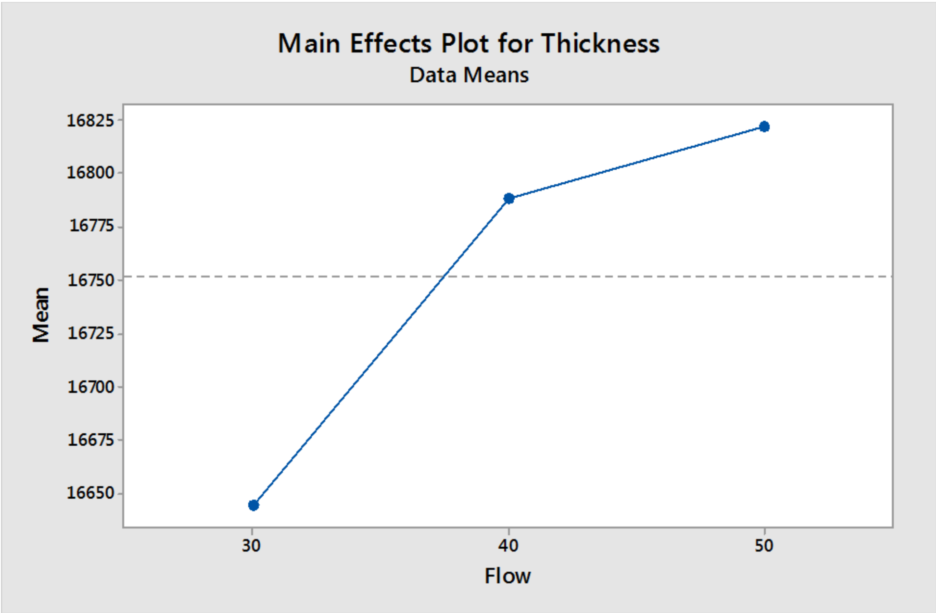

Figure 6. Main effect plot

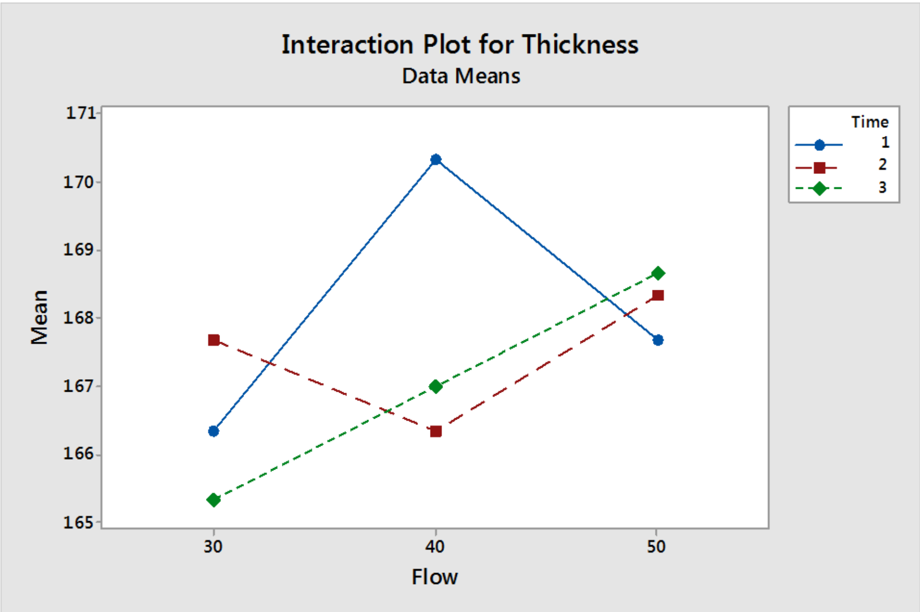

Figure 7. Interaction plot

This interaction effect indicates that the relationship between flow and mean thickness depends on the value of the holding time, as shown in Figure 7. Higher thickness value has resulted when the holding time is 1 second and the flow is 40% compared with the other cases when the holding time is 2 or 3 seconds. This means that the effect of flow is coupled with the state of the holding time.

Conclusion

In the present study, a design of experiment tools was used to study the effect of three factors on the quality of the final hollow conical-shaped parts made using reciprocating screw blow injection molding process. Three factors in the injection process were considered: holding time, holding pressure, and flow. Full factorial design was built and the wall thickness of the resulted part was measured. The ANOVA results have shown that the main effect of flow and the interaction between flow and holding time were significant at a 95% confidence level. For the main effect of flow, the results have shown that greater flows have produced higher thickness means of the molded part. It was also found that the effect of the holding time on the thickness significantly depends on the level of flow. Therefore, they need to be controlled simultaneously during the stages of improvement.

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