O-04-630

OPTIMIZATION PARAMETERS OF INJECTION MOULDING MACHINE FOR REDUCING WARPAGE OF DOG BONE PLASTIC PART

M. Amran*, S. Salmah, M. Zaki, R. Izamshah, M. Hadzley, S. Sivarao and N.I. Syahriah
Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya 76100 Durian Tunggal, Melaka, Malaysia – mohdamran@utem.edu.my

Abstract - The optimization of processing parameters on warpage of polypropylene (PP) in the application of injection moulding machine was studied. The appropriate parameters were adjusted to reduce the warpage defect on the tensile test specimen of dog bone. The type of injection moulding machine used in this research is Arburg 420C 800-250C. Four parameters that have been investigated; injection pressure, clamping pressure, back pressure and holding pressure. A concept of design of experiment (DOE) has been applied using Taguchi method to determine the suitable parameters. To measure the warpage of the dog bone, digital height gauge was used to measure the flatness of the part surface. According the analysis of variance (ANOVA), the most significant factor that effect the warpage was holding pressure by 57.82%, followed with back pressure by 25.75%, clamping pressure by 16.27% and injection pressure by 0.16%. It is found that the optimum parameters setting that have been obtained were injection pressure at 950 bar, clamping pressure at 600 kN, holding pressure at 700 bar and back pressure at 75 bar. The depreciation value of warpage minimum index in this experiment was decreased by 4.6% after confirmation run.

Keywords: Injection Moulding, Polypropylene, Warpage, Taguchi Method, Injection Parameters.

Introduction

The parameters of injection moulding machine are very important for polymer processing operation in the plastic industry today [1]. The quality of the final product is mainly dependent on the moulding process parameters [2]. The main moulding parameters in injection moulding are; material melt temperature, mold temperature, injection time and required pressure. Some researches choose molding parameters according to the material type and molding geometry and then implement them to assess the molding quality. If there are any variations, iterative corrective actions are performed to reach the quality requirements [3]. However, some defects are still found in the plastics parts. For example, to produce thinner plastic part such as casing and housing of products which have thin shell feature, the significant warpage defect still appeared [4]. In this study, optimization parameter of injection moulding machine for reducing warpage of dog bone plastic part is investigated by using design of experiment (DOE) by Taguchi method.

Experimental

The polymer used in this study was general polypropylene (PP). Arburg 420C 800-250C injection moulding machine was selected. Table 1 shows the general advantages and disadvantages of PP polymer.

Table 1: Advantages and disadvantages of PP

Advantages	Disadvantages
• Low coefficient of friction • Good fatigue resistance • Good impact strength • Excellent flexural strength • Good grade availability	• Poor weatherability • Flammable • Difficult to bond • Broken down by ultraviolet radiation

Almost all the thermoplastics and some thermoset plastics can be injected by injection moulding machine thus adding to the flexibility of the process in this injection moulding machine. Table 2 shows the factors and working level of design factor in Taguchi method. Four factors and three levels were used in this experiment. There are 9 trial processes and each trial are be done for 3 times. This means that 27 injection processes were done to get the most accurate result.

Table 2: Factors and working level of design factor

Symbol	Factor (Pressure)	Level 1	Level 2	Level 3
A	Injection (bar)	900	950	1000
B	Clamping (kN)	550	600	650
C	Holding (bar)	500	600	700
D	Back (bar)	60	75	90

Legend : A for Injection Pressure (bar)
: B for Clamping Pressure (kN)
: C for Holding Pressure (bar)
: D for Back Pressure (bar)

After specimen was produced, the value of the warpage was measured by using the digital height gauge and then the average of the measurement is calculated. Then, by using the results that obtained from the data, analysis was done using the MINITAB software to get the optimum parameter value.

Results and Discussion

Experimental Result

Table 3 shows the summarization of the data that was collected from the experiment. Four factors of pressure were selected for this experiment. There are injection pressure (A), clamping pressure (B), holding pressure (C), and back pressure (D). It is found that the maximum value of deflection (Za) was 0.3276 mm in trial no 1 and minimum value of deflection (Za) was 0.2563 mm in the trial no 3.

Table 3: Summarization of experimental result

No	A (bar)	B (kN)	C (bar)	D (bar)	Average Za (mm)
1	900	550	500	60	0.3276
2	900	600	600	75	0.2914
3	900	650	700	90	0.2563
4	950	550	600	90	0.3239
5	950	600	700	60	0.2722
6	950	650	500	75	0.2721
7	1000	550	700	75	0.2663
8	1000	600	500	90	0.2814
9	1000	650	600	60	0.327

Analysis of Signal to Noise (S/N) Ratio

Taguchi method uses the S/N ratio to measure quality characteristic deviating from the desired value. The aim of this study is to minimize the warpage index within optimal process parameter; the smaller the better quality characteristic was selected in this study. Table 4 shows the S/N ratio value that calculates using MINITAB software. It is found that the highest value of S/N ratio was 11.825 in trial no 3 and the lowest S/N ration value was 9.6931 in trial no 1. According to the value of deflection (Za) as shown in Table 3 and S/N ratio as shown in Table 4, it shows that the different value of the data. This means, the increase value of the deflection will result the decreasing value of the S/N ratio and vice versa. The S/N ratio value also can be calculated using equation 1.

$$-10\log(\text{MSD}) \quad \text{where} \quad \text{MSD} = \frac{1}{n}\sum_{i=1}^{n} y_i^2 \qquad \text{Eq. 1}$$

Where MSD is the mean square deviation, y the observation or data and n is the number of test in a trial.

Table 4: Summarization of S/N ratio

No	A (bar)	B (kN)	C (bar)	D (bar)	S/N
1	900	550	500	60	9.6931
2	900	600	600	75	10.7102
3	900	650	700	90	11.825
4	950	550	600	90	9.7918
5	950	600	700	60	11.3022
6	950	650	500	75	11.3054
7	1000	550	700	75	11.4926
8	1000	600	500	90	11.0135
9	1000	650	600	60	9.709

Determination of S/N Ratio Response Table

The S/N ratio response table for each process parameters at the level of 1, 2 and 3 was created by utilizing the S/N ratio values for warpage in the Table 5. Based on the data from Table 5, the S/N response diagram has been constructed as shown in Fig. 1.

Table 5: The responses table of S/N ratio

Level	A (bar)	B (kN)	C (bar)	D (bar)
Level 1	10.74	10.33	10.67	10.23
Level 2	10.80	11.01	10.07	11.17
Level 3	10.74	10.95	11.54	10.88
Difference	0.06	0.68	1.47	0.93

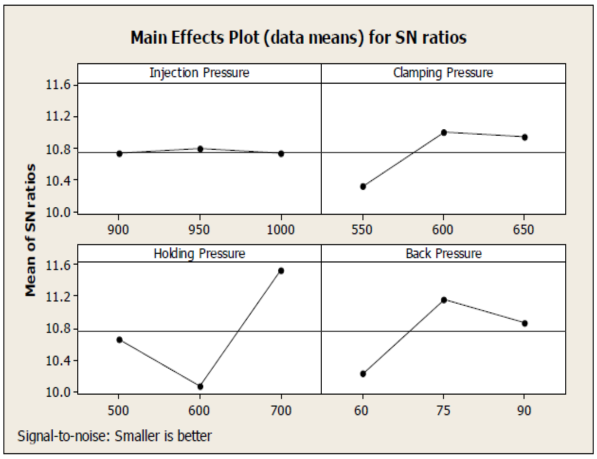

Figure 1: Main effect plot for S/N ratio

Based on the observation on the graphs, in Fig. 1, injection pressure the highest value is at level 2 which is 10.80 of S/N ratio and the pressure is 950 bar. Further, clamping pressure shows an increasing value where the highest value obtained is at level 2, where the S/N ratio is 11.01 in which the pressure is 600 kN. Furthermore, in holding pressure, the maximum value obtained from the graph is at level 3 with the S/N ratio 11.54 and pressure of 700 bar. For back pressure, the maximum value obtained is at level 2, S/N ratio of 11.17 at pressure 75 bar. That means, the most significant factor that affecting warpage are holding pressure and back pressure followed by clamping pressure and injection pressure.

Analysis of Variance (ANOVA)

The analysis of variance (ANOVA) is to be carried out to examine the influence of process parameters on the quality characteristic in this study**,** the ANOVA will compute the quantities such as degrees of freedom (f), sums of squares (S), variance (V), F-ratio (F), and percentage contribution (P%) as illustrated in Table 6.

Table 6: ANOVA computation using minitab software

Source	f	S	V	F	P (%)
A (bar)	2	0.00001	5.0×10^{-6}	-	0.16
B (kN)	2	0.00103	5.15×10^{-4}	-	16.27
C (bar)	2	0.00366	1.83×10^{-3}	-	57.82
D (bar)	2	0.00163	8.15×10^{-4}	-	25.75
Pooled Error	0	0	0	-	
Total	8	0.00633	3.165×10^{-3}	-	100

According Table 6, the highest value of percentage contribution (P) was in the holding pressure column, it record that 57.82% of P value. This is followed by back pressure at 25.7% of P value. The P value for clamping pressure was 16.27% and the lowest one of P value was 0.16% at injection pressure column. It shows that holding pressure, back pressure and clamping pressure are the significant factor while injection pressure is not much affecting the warpage defect.

Confirmation Run

After the optimal levels of all the control factors were identified, i.e., injection pressure at 950 bar, clamping pressure at 600 kN, holding pressure at 700 bar and back pressure at 75 bar, the last step in Taguchi parameter design is conducting the confirmation run. The combination of the optimal levels of all the factors produces the minimal index of warpage. Table 7 shows the result for non-optimum and optimum process of injection moulding.

Table 7: Result non-optimum and optimum process

	A (bar)	B (kN)	C (bar)	D (bar)	Za (mm)
Non-optimum	900	650	700	90	0.2563
Optimum	950	600	700	75	0.2455

According to the result from Table 7, the percentage of depreciation value of warpage can be determined. The percentage of depreciation of this experiment is 4.6%. The values of warpage after the experiment are decreased because some of the parameters before the experiment are set out of the recommended value of the machine manual.

$$Depreciation\ (\%) = \frac{Before - After}{Before} \text{ X } 100$$

$$= \frac{0.2563 - 0.2445}{0.2563} \text{ X100}$$

$$= 4.6\%$$

Conclusions

In this study, the optimization process of injection molding parameters is investigated. Taguchi method was used to find the optimum parameters that influence the warpage defect in dog bone tensile specimen. The S/N ratio and ANOVA analysis were utilized to find the optimum parameters. In conclusion, by using the S/N ratio the optimum parameter that can minimize the warpage defect was injection pressure at 950 bar, clamping pressure at 600 kN, holding pressure at 700 bar and back pressure at 75 bar. From ANOVA analysis, the most significant factor that affects the warpage is holding pressure by 57.82% of contribution, followed with back pressure by 25.75% and clamping pressure by 16.27%. Injection pressure is almost less significant factor which only contributes about 0.16%. The deflection of warpage was decreased to 4.6% after confirmation experiments.

Acknowledgements
The authors gratefully acknowledge Universiti Teknikal Malaysia Melaka (UTeM) for supported the word under Short Term Research Grant (PJP/2012/FKP (25B) S1028).

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