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Optimization of Injection Moulding Process using Taguchi and ANOVA

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Abstract— Now a day's demand of plastics product is very high because of their better quality, design and appearance in comparison to other material product. The use of best operating parameters is needed to produce better quality of plastics product. This paper deals with the effects of parameters selection on injection moulding using Taguchi and ANOVA. The objective of this paper is to define suitable parameters in producing plastic product in term of strength. The paper describes the effect of temperature, pressure and cooling time. Plastic material polycarbonate was studied in this paper which commonly used in industries. The operating parameters have to be correct and can produce better product. There is changes occurs in product with change in parameters. Optimum parameter is related to the quality to produce product without defects such as short moulding, flashing and others.

Plastic product (Tea Plate) of polycarbonate plastic material is produced with De-Tech85 LNC5 injection moulding machine with different melt temperature, injection pressure, and cooling time. Tensile strength test of each workpiece has done with Tinius Olsen H10K-T UTM. Each plate has shown different strength, surface finish and some differences in other properties. By using Taguchi and ANOVA an optimum value or the best value of melting temperature, injection pressure and cooling time is obtained.

Index Terms— ANOVA, plastic injection moulding, polycarbonate, tensile strength, Taguchi

1 INTRODUCTION

The injection Moulding is the most salient process for plastic parts mass production. Among the all plastic products about one third are made by injection moulding, and for the injection moulding process over half of the world's polymer processing equipment is used [1]. Selecting the proper injection moulding process settings is crucial because during shaping the behavior of the polymeric material is highly influenced by the process parameters. Consequently, the process parameters govern the quality of the part produced. A substantial amount of research has been directed towards determining the process settings for the injection moulding process as well as the optimal location of the injection gate. There are many parameters which affect the properties of plastic product. Melting temperature, injection pressure and cooling time are the main processing parameters. There are different processing parameters for all different materials.

Polycarbonate plastic consists of high impact-resistance, very light with dimensional stability, stronger, optical clarity, and heat resistance and very good as an electrical insulator. It is highly transparent and has better light transmission characteristics than many kinds of glass. The property of polycarbonate to undergo large plastic deformations without cracking or breaking makes it different from most thermoplastics. So, this thesis demonstrates a process for finding the Optimum parameters for producing polycarbonate plastic products with high strength.

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2 EXPERIMENTAL PROCEDURE

In this project polycarbonate as a raw material is used to produce tea plate with the help of De-Tech85 LNC5 injection moulding machine. Polycarbonate is processed by using different combinations of processing parameters. Different combinations of melt temperature, injection pressure and cooling time have taken and polycarbonate tea plate and test specimen is produced. After this, tensile test of the all specimen has done by using Tinius Olsen H10K-T universal testing machine.

2.1 Design of experiment

The design of experiment by means of Taguchi method is selected to identify the best set of parameters among the effective factors by cutting down a number of experiments. The major steps to complete an effective designed experiment are: [2]

A. Factors Selection
B. Selection of Orthogonal Array and Factor Levels
C. Conduct tests described by trials in orthogonal arrays
D. Analyze and Interpret results of the experimental trials

A. Factor selection

In injection moulding there are a number of possible factors that produce significant effects on tensile strength which are mould temperature, filling time, gate dimensions, injection pressure, melt temperature and cooling time [3]. In this experiment, the factors taken into considerations are only melt temperature, injection pressure and cooling time.

B. Selection of Orthogonal Array and Factor Levels

In an L16 (4^3) orthogonal array four levels of each factor are conducted where the selection of the array is because of its suitability for three factors with four Levels [2]. The L16 (4^3)

orthogonal array is shown in Table 1. The four different levels of melt temperature are chosen based on the thermal properties of Polycarbonate. The levels and factors suggested are all shown in Table 2.

TABLE 1
L16 (4^3) ORTHOGONAL ARRAY

Trial No.	Column No.		
	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	1	4	4
5	2	1	2
6	2	2	1
7	2	3	4
8	2	4	3
9	3	1	3
10	3	2	4
11	3	3	1
12	3	4	2
13	4	1	4
14	4	2	3
15	4	3	2
16	4	4	1

TABLE 2
LEVELS AND SELECTED FACTORS

Factors	Levels			
	1	2	3	4
Melt temperature,A (^oC)	260	280	300	320
Injection pressure,B (bar)	90	110	130	150
Cooling Time,C (Sec.)	7.5	15	22.5	30

C. Conduct tests described by trials in orthogonal arrays

The tests are conducted on De-Tech85 LNC5 injection moulding machine according to the sets of control factors (processing parameters) obtained from trials of orthogonal array. The control factors and levels of control factors according to orthogonal array are shown in Table 3.

TABLE 3
CONTROL FACTORS AND LEVELS FOR FACTOR A, B & C

Trial No.	Control Factor		
	A	B	C
1	260	90	7.5
2	260	110	15
3	260	130	22.5
4	260	150	30
5	280	90	15
6	280	110	7.5
7	280	130	30
8	280	150	22.5
9	300	90	22.5
10	300	110	30
11	300	130	7.5
12	300	150	15
13	320	90	30
14	320	110	22.5
15	320	130	15
16	320	150	7.5

D. Analyze and Interpret results of the experimental trials

The tensile test of specimen produced during above tests is completed on Tinius Olsen H10K-T universal testing machine. The tensile strength of each test specimen produced according to trials of orthogonal array is shown in Table 4.

The tensile strength obtained is used to calculate the signal-to-noise (S/N) ratio to obtain the best setting of the parameters arrangement. Signal to noise (S/N) ratio is calculated as shown in Table 4. The results obtained are analysed by using analysis of variance (ANOVA). The significance of factors to affect strength is determined by calculating the percentage of contribution from this method.

TABLE 4

SUMMARY OF RESULTS OF TENSILE STRENGTH TESTS AND S/N VALUES

Trial No.	Control Factor			Tensile Strength (MPa)	S/N Ratio
	A	B	C		
1	260	90	7.5	61.40	35.7633
2	260	110	15	60.90	35.6923
3	260	130	22.5	60.30	35.6063
4	260	150	30	62.10	35.8618
5	280	90	15	59.20	35.4464
6	280	110	7.5	59.80	35.5340
7	280	130	30	59.90	35.5485
8	280	150	22.5	59.80	35.5340
9	300	90	22.5	60.30	35.6063
10	300	110	30	59.90	35.5485
11	300	130	7.5	60.30	35.6063
12	300	150	15	59.85	35.5412
13	320	90	30	59.80	35.5340
14	320	110	22.5	60.20	35.5919
15	320	130	15	60.28	35.6034
16	320	150	7.5	60.70	35.6637

3 RESULTS AND DISCUSSION

Strength of injection moulded product is necessary. Therefore, the higher the strength is better and S/N ratio is calculated for higher the better. For calculating S/N ratio for this case of higher the better Taguchi has outlined an equation. The equation to obtain the values of S/N ratio is shown below [4]:

$$S/N = -10\log_{10}(MSD)$$

For larger is better

$$MSD = \frac{1}{n}\sum\frac{1}{y_i^2}$$

MSD = Mean Square Deviation
y = Observations
n= No. of tests in a trial.
Since for trial no. 1
n = 1 and y = 61.40

Therefore,

$$S/N = -10\log_{10}\frac{1}{1}(\frac{1}{61.40^2})$$

$$S/N = 35.7633$$

Similarly S/N ratio for other trials is obtained and show in Table 4.
S/N ratio for Level 1 of melt temperature is obtained as follows:

$$Level\,1 = \frac{(35.7633 + 35.6923 + 35.6033 + 35.8618)}{4}$$

$$= 35.7309$$

Similarly the S/N ratio for each level of each factor is obtained and the results of S/N ratio for each level are shown in table 5.

TABLE 5

RESPONSE TABLE OF S/N RATIO FOR EACH LEVEL OF EACH FACTOR

Level	A	B	C
1	35.7309	35.5875	35.6418
2	35.5157	35.5916	35.5708
3	35.5755	35.5911	35.5846
4	35.5982	35.6501	35.6232
Max. Difference	0.2152	0.0626	0.071

From the S/N ratio response as shown in Table 5, the best combination of parameters can be identified by selecting the highest difference value from each factor. In this case, the most significant factor that has an effect on strength are melt temperature (A) followed by cooling time (C) and injection pressure (B). Table 6 shows the summary of best combinations of parameters.

TABLE 6

BEST COMBINATION OF PARAMETERS

Factor	Values
Melt Temperature (A)	260 °C
Injection Pressure (B)	150 Bar
Cooling Time (C)	7.5 Sec.

By using minitab16 software the main effects plot for S/N ratios is obtained and shows in fig.1.

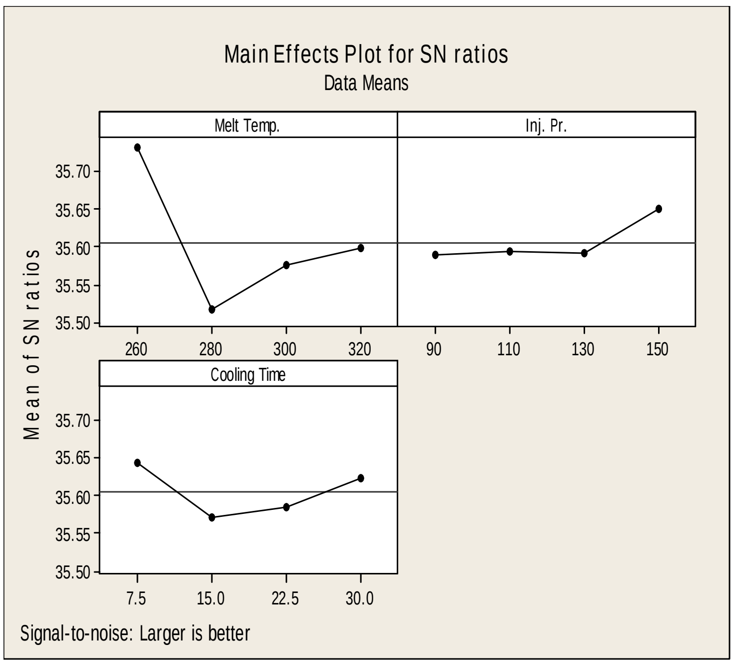

Fig. 1 Main Effect Plot for SN ratios

3.1 ANOVA calculation

First of all calculate the degree of freedom for all factors and degree of freedom is calculated as shown below:

Total degree of freedom

$$f_T = N - 1$$

Where N = no. of trials

$$f_T = 16 - 1 = 15$$

For factor A

$$f_A = k_A - 1$$

Where k_A = No. of levels for factor A

Therefore $f_A = 4 - 1 = 3$

Similarly, $f_B = 3$ and $f_C = 3$

For error, $f_e = f_T - (f_A + f_B + f_C)$

Therefore, $f_e = 15 - (3 + 3 + 3) = 6$

After this sum of squares for all factors is calculated and sum of square is calculated as shown below:

Total sum of squares

$$S_T = (T_{S_1}^2 + T_{S_2}^2 + ... + T_{S_N}^2) - \frac{(T_{S_1} + T_{S_2} + ... + T_{S_N})^2}{N}$$

$$S_T = (61.4^2 + 60.9^2 + 60.3^2 + ... + 60.7^2) - \frac{(61.4 + 60.9 + 60.3 + ...60.7)^2}{16}$$

$$S_T = 7.4625$$

For factor A

$$S_A = \left(\frac{(\sum A_1)^2}{k_{A_1}} + ... + \frac{(\sum A_4)^2}{k_{A_4}}\right) - \frac{(T_{S_1} + T_{S_2} + ... + T_{S_N})^2}{N}$$

$$S_A = \frac{(61.40 + 60.90 + 60.30 + 62.10)^2}{4} + \frac{(59.20 + 59.80 + 59.90 + 59.80)^2}{4} + \frac{(60.30 + 59.90 + 60.30 + 59.85)^2}{4} + \frac{(59.80 + 60.20 + 60.28 + 60.70)^2}{4} - \frac{(61.40 + 60.90 + ... + 60.70)^2}{16}$$

$$S_A = 4.8173$$

Similarly, for factor B

$$S_B = \left(\frac{(\sum B_1)^2}{k_{B_1}}\right) + ... + \left(\frac{(\sum B_4)^2}{k_{B_4}}\right) - \frac{(T_{S_1} + T_{S_2} + ... + T_{S_N})^2}{N}$$

$$S_B = 0.5369$$

For factor C

$$S_C = (\frac{(\sum C_1)^2}{k_{C_1}}) + ... + \frac{(\sum C_4)^2}{k_{C_4}}) - \frac{(T_{S_1} + T_{S_2} + ... + T_{S_N})^2}{N}$$

$$S_C = 0.6374$$

For error

$$S_e = S_T - (S_A + S_B + S_C)$$

$$S_e = 1.4709$$

Then the values of variance for all factors are calculated as shown below:

For factor A

$$V_A = \frac{S_A}{f_A}$$

$$V_A = \frac{4.8173}{3} = 1.6057$$

Similarly for factor B, $V_B = \frac{S_B}{f_B}$

$$V_B = \frac{0.5369}{3} = 0.1789$$

For factor C, $V_C = \frac{S_C}{f_C}$

$$V_C = \frac{0.6374}{3} = 0.2124$$

For variance error, $V_e = \frac{S_e}{f_e}$

$$V_e = \frac{1.4709}{6} = 0.24515$$

After this the F-Ratio for all factors are calculated as shown below:

For factor A, $F_A = \frac{V_A}{V_e}$

$$F_A = \frac{1.6057}{0.24515} = 6.54$$

Similarlly for factor B, $F_B = \frac{V_B}{V_e}$

$$F_B = \frac{0.1789}{0.24515} = 0.72975$$

For factor C, $F_C = \frac{V_C}{V_e}$

$$F_C = \frac{0.2124}{0.24515}$$

At the last the percentage contribution P (%) for all the factors are calculated as shown below:

For factor A, $P_A = (\frac{S_A}{S_T}) \times 100$

$$P_A = (\frac{4.8173}{7.4625}) \times 100 = 64.5534\%$$

For factor B, $P_B = (\frac{S_B}{S_T}) \times 100$

$$P_B = (\frac{0.5369}{7.4625}) \times 100 = 7.1946\%$$

For factor C, $P_C = (\frac{S_C}{S_T}) \times 100$

$$P_C = (\frac{0.6374}{7.4625}) \times 100 = 8.5413\%$$

TABLE 7

ANALYSIS OF VARIANCE FOR TENSILE STRENGTH

Factors	f	S	V	F	p (%)
Melt Temp.	3	4.8173	1.6057	6.54	64.55
Injection	3	0.5369	0.1789	0.7297	7.1946
Cooling	3	0.6374	0.2124	0.8664	8.5413
Error	6	1.4709	0.2451		19.71
Total	15	7.4626	2.2421		100

In Table 7, f = Degree of freedom, S= Sum of squares, V = Values of variance, F = F- Ratio, p (%) = Percentage contribution.

The percentage of contributions p (%) for all factors is shown in Table 7. This results shows that the melt temperature contribute the most by 64.55% and this is followed by cooling time by 08.54% and injection pressure 07.19% . This proves that melt temperature is the most significant parameter contribute to improve tensile strength in the process while cooling time and injection pressure only have small effects towards the tensile strength.

4 Conclusion

In injection moulding process of Polycarbonate, for tensile strength melt temperature is found to be the most significant factor which contributes 64.55% followed by cooling time by 08.54% and injection pressure 07.19%. The results show that, for polycarbonate the best combination of processing parameters in terms of tensile strength are 260 ^{o}C melting temperature, 150 bar injection pressure and 7.5 seconds 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.

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6 Future Scope

Recommendations for future research in the injection moulding would include investigating best combination of parameters for tensile strength of other plastic materials. Optimum parameters for tensile strength of polycarbonate are obtained in this paper, in future optimum parameters for hardness and good surface finish of different materials may also obtain. We used Taguchi method for obtaining the optimum processing parameters combination for a single quality characteristic only that is tensile strength. Since, the Taguchi method does not give any consideration to the relationship between multiple quality characteristics and processing parameters [4]. Therefore Grey relational analysis may be use to obtain the optimum processing parameters combinations for multiple quality characteristics in the mean time.

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