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Original Research Article

EFFECTS ON PRODUCT PART DURING CHANGING THE PROCESSING PARAMETERS OF POLYPROPYLENE MATERIAL

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Abstract: Production of plastic products by plastic Injection molding process is one of the most widely used process in recent scenario. The appearances of plastic injection molding procedures are affected by the quality of the plastic products by their different level of process parameters. The effect on product parts on various level of process parameters is become a research issue and is now known as finding the efficient frontier of the parameters for good product. The objective of this research paper is to determine the optimized value of input parameters which affects the cycle time and product part in plastic injection molding process during manufacturing of a small container cap with polypropylene work material. In this paper find the optimized parameters like melting temperatures, injection pressure, speed and filling time are used to find the effect on product parts of polypropylene wok material in plastic injection molding process with a number of experiments conducted on plastic injection molding machine which optimize by Taguchi and ANOVA based on responses.

Keywords: - Plastic injection molding, Processing parameters, Polypropylene material, Taguchi and ANOVA.

Introduction: Injection molding is considered one of the most communal plastic part manufacturing processes. Used for producing quantities from both thermoplastic and thermo-set polymers. The process commonly initiates with taking the polymers in the form of pellets or granules and heating them to the molten state [2]. The melt is then injected into a chamber formed by a split-die mold. The melt remains in the mold and is either chilled down to solidify or heated up to cure (thermo-sets). The mold is then opened and the part is ejected [3]. Instead of the relatively expensive tooling cost, injection molding remains the most popular manufacturing process for plastic materials in mass production, it has low operational cost, high throughput, and flexible to make parts with complex shapes.

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Process Cycle of Injection Molding

The process cycle of injection molding is very short, between 2 seconds and 2 minutes, and consists of the following four stages:

Clamping- The two halves of the mold must be securely closed by the clamping unit. Both half of the mold is attached to the injection molding machine and one half is allowed to slide. The hydraulically powered clamping unit forcefully pushes the mold halves together and exerts sufficient force to keep the mold securely closed while the material is injected. The time required to close and clamp the mold is dependent upon the machine - larger machines will require more time.

Injection- The raw plastic material in the form of pellets, is fed into the injection molding machine, and advanced towards the mold by the injection unit. During this process, the material is melted by heat and pressure [3]. The melted plastic is then injected into the mold very quickly and the buildup of pressure packs and holds the material. The amount of material that is injected is referred to as the shot [5]. The injection time is difficult to calculate accurately because of the complex and changing flow of the molten plastic into the mold. The injection time can be calculated by the shot volume, injection pressure, and injection power.

Cooling- The molten plastic is allowed to cool it will solidify into the shape of the desired part. During cooling some shrinkage of the part may be occur. The packing of material in injection stage it allows additional material to flow into the mold and reduce the amount of visible shrinkage. The mold can't be opened until the required cooling time has elapsed. The cooling time is to be estimated from several thermodynamic properties of the plastic and the maximum wall thickness of the part.

Ejection- The cooled part may be ejected from the mold by the ejection system, which is attached to the rear half of the mold. When the mold is opened, a mechanism is to be used to push the part out of the mold. Some force must be applied to eject the part because during cooling the part shrinks and adheres to the mold. A mold release agent is used in the mold cavity for easy removal of part. The time that is required to open the mold and eject the part can be calculated from the dry cycle time of the machine and time for the part to fall free from the mold. Once the part is to be ejected, the mold can be clamped shut for the next shot.

Plastic injection molding machine:

Fig 1: Plastic injection molding machine (CIPET Raipur)

Objective of Work: The main objective of this work is to make a good product with better quality using Polypropylene material of grade M110 by using plastic injection molding machine and optimized the processing parameters using Taguchi and ANOVA. Polypropylene material is economic and chip. It used for making domestic products that's why we use Polypropylene material.

The objectives which are going to perform in this work are:

1. Select the parameters of experiment for production.
2. Design the experiment to be performed.
3. Performed the experiments as per parameters are design.
4. Observe the defects, product quality and total cycle time.
5. Applying Taguchi and ANOVA to optimize the processing parameters.

Methods and Material: In this project polypropylene as a raw material is used to produce a small container cap with the help of STD-90 CRPR/PROC/MPCIMM/37 injection molding machine. Polypropylene is processed by different combinations of processing parameters. Different combinations of injection pressure, injection speed, melt temperature and injection time is taken and polypropylene small container cap and test specimen is produced. During each test observe the cycle time and effect on product part.

Material used - Polypropylene is a “thermoplastic” addition polymer made from the combination of propylene monomers. Polypropylene is used in a variety of applications including packaging for consumer products, industries including the automotive industry, and textiles. Polypropylene is a very useful plastic for injection molding and is typically available in the form of pellets. Polypropylene is easy to mold and it flows very well because of its low melt viscosity. This property significantly enhances the rate of filling of material into the mold. Shrinkage in polypropylene material is about 1-2% but can vary based on a number of factors, including holding pressure, holding time, melt temperature, mold wall thickness, mold temperature, and the percentage and type of additives.

Fig 3.1: Polypropylene M110 (CIPET Raipur)

Design of Experiment: Design of experiment is a systematic approach for investigation of a system or process. It is important for maximizing information gained while minimizing the resources required. It has more to offer than a single change in time of experimental methods, because it allows a judgment on the significance to the output of input variables acting alone, also the input variables acting in the combination with one another. Design of experiment is a team oriented and a variety of backgrounds should be involved when identifying factors and levels and developing the matrix as this is the most skilled part. The design of experiment should have a clear understanding of the difference between control and noise factors. It is very crucial to get information from each experiment that has performed.

The design of experiment 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 taken to complete an effective designed experiment are:

1. Factor selection
2. Selection of orthogonal array and factor levels
3. Conduct tests described by trials in orthogonal arrays
4. Analyze and interpret results of the experimental trials.

Factor selection: In injection molding there are a number of possible factors that produce significant effects on cycle time which are mould temperature, filling time, gate dimensions, injection pressure, melt temperature, holding time and cooling time. In this experiment, the factors taken into considerations are only injection pressure, injection speed, melting temperature and cooling time.

Selection of orthogonal array and factor levels

In an L16 orthogonal array four levels of each factor are conducted where the selection of the array is because of its suitability for four factors with four Levels. The L16 orthogonal array is shown in Table 1. The four different levels of injection pressure, injection speed, melting temperature and injection time are chosen based on the thermal properties of Polypropylene. The levels and factors suggested are all shown in Table 2.

Table 3.1 L16 orthogonal array

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

Table 3.2 Levels and selected factors

Factors	Levels			
	1	**2**	**3**	**4**
(A) Injection pressure (psi)	95	100	135	139
(B) Injection speed (mm/s)	65	70	75	80
(C) Melting temperature (°C)	170	203	210	220
(D) Injection time (sec)	2	5	10	15

Conduct Tests : The tests are conducted on STD-90 CRPR/PROC/MPCIMM/37 injection molding machine according to the sets of control factors (processing parameters) obtained from trials of orthogonal array.

Analyze and interpret results of the experimental trials: The cycle time of specimens are observed during the above tests from the control panel of machine. The cycle time of each test specimens produced according to trials of orthogonal array. The cycle time obtained is used to calculate the signal-to-noise (S/N) ratio to obtain the best setting of the parameters arrangement. Cycle time of injection molding observation is necessary. Therefore, the smaller the cycle time is better and S/N ratio is calculated for smaller is better.

Table 4 Summary of results of cycle time and S/N Ratio

Trial No.	Control factors				Cycle time (sec)	S/N Ratio
	A	B	C	D		
1	95	65	170	2	22	-26.7272
2	95	70	203	5	23	-27.7402
3	95	75	210	10	18	-25.5804
4	95	80	220	15	25	-27.0994
5	100	65	203	10	30	-28.6831
6	100	70	170	15	32	-30.5779
7	100	75	220	2	20	-26.5263
8	100	80	210	5	28	-28.8220
9	135	65	210	15	24	-28.1099
10	135	70	220	10	23	-27.1133
11	135	75	170	5	30	-28.6831
12	135	80	203	2	27	-29.1022
13	139	65	220	5	18	-25.5804
14	139	70	210	2	23	-26.3752
15	139	75	203	15	26	-28.1783
16	139	80	170	10	25	-28.4645

Results and Discussion: For calculating S/N ratio for this case of smaller the better Taguchi has outlined an equation. The equation is to obtain the values of S/N ratio is shown,

For smaller is better

$$S/N = -10\log_{10}[\sum(y^2/n)]$$

y = Observations

n = Number of test in trials

Since for trial no. 1 n = 1, y = 22

$$S/N = -10\log_{10}(22^2/1)$$

$$S/N = -26.72$$

Response Table for Signal to Noise Ratios

For Smaller is better

S/N Ratio for level 1 injection pressure is obtained as follows:

$$\text{Level 1} = \frac{-26.7272-27.7402-25.5804-27.0994}{4}$$

$$= -26.79$$

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 5.1.

Table 5.1 Response table of S/N Ratio for each level of each factor

Level	A	B	C	D
1	-26.79	-27.28	-28.61	-27.18
2	-28.65	-27.95	-28.43	-27.71
3	-28.25	-27.24	-27.22	-27.46
4	-27.15	-28.37	-26.58	-28.49
Delta	1.87	1.13	2.03	1.31
Rank	2	4	1	3

From the S/N ratio response as shown in Table 5.1, the best combination of parameters can be identified by selecting the smallest value from each factor to minimize the cycle time. In this case, the most significant factor that has an effect on cycle time is injection pressure (A), injection speed (B), melting temperature (C) and injection time (D). Table 5 shows the summary of best combinations of parameters.

Table 5.2 Summary of best combinations of parameters

Factor	Values
Injection pressure (A)	95 psi
Injection speed (B)	75 mm/s
Melting temperature (C)	220 °C
Injection time (D)	2 sec

By using minitab16 software the main effects plot for S/N ratios is obtained and shows in fig 5.

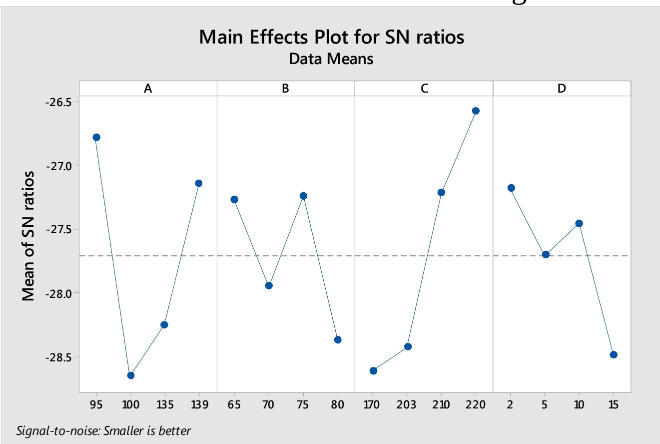

Fig 5: Main effect plot for S/N ratio

The results obtained from Taguchi are analyzed by using analysis of variance (ANOVA). The significance of factors to affect the cycle time is determined by calculating the percentage of contribution from this method.

6. ANOVA Calculation

First 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

$$f_T = 16 - 1$$

$$f_T = 15$$

For factor A

$$f_A = k_A - 1$$

Where k_A = No. of levels for factor A

Therefore, $f_A = 4 - 1 = 3$

Similarly, $f_B = 3$, $f_C = 3$, $f_D = 3$

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

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

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

Total sum of squares

$$S_T = (T_{s1}^2 + T_{s2}^2 + \ldots\ldots + T_{sN}^2) - (T_{s1} + T_{s2} + \ldots.. + T_{sN})^2 / N$$

$$S_T = 255.75$$

For factor A

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

$$S_A = 78.25$$

Similarly calculating for all factors S_B, S_C, and S_D are shown in Table 5.4

For error $S_e = S_T - (S_A + S_B + S_C + S_D) = 36.25$

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

For factor A

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

$$V_A = 26.25$$

Similarly calculating for all factors V_B, V_C, and V_D are shown in Table 5.4

For variance error $V_e = \frac{S_e}{f_e} = 12.083$

F-Ratio for all factor are calculated as follows,

For factor A,

$$F_A = \frac{V_A}{V_e} = \frac{26.25}{12.083} = 2.17$$

Similarly calculating for all factors F_B, F_C and F_D are shown in Table 5.4

The percentage contribution P (%) for all the factors are calculated and shown in Table 6.

General Linear Model: Cycle Time versus A, B, C, D Method

Table 6.1 Analysis of variance for cycle time

Source	F	S	V	F - Value	P-Value
A	3	78.75	26.250	2.17	0.270
B	3	22.25	7.417	0.61	0.651
C	3	88.25	29.417	2.43	0.242
D	3	30.25	10.083	0.83	0.557
Error	3	36.25	12.083		
Total	15	255.75			

Regression Equation

Cycle time = 24.625 - 2.62 A_95 + 2.87 A_100 + 1.37 A_135 - 1.62 A_139 - 1.13 B_65 + 0.63 B_70 - 1.13 B_75 + 1.63 B_80 + 2.63 C_170 + 1.88 C_203 - 1.37 C_210 -3.13 C_220 - 1.63 D_2 + 0.13 D_5 - 0.63 D_10 + 2.13 D_15

Prediction for Cycle Time

General Linear Model Information

Settings, A = 95, B = 65, C= 170, D = 2

Prediction

Fit	SE Fit	95% CI	95% PI
21.875	3.13332	(11.9034, 31.8466)	(6.98161, 36.7684)

Settings, A = 100, B= 70, C = 203, D = 5

Prediction

Fit	SE Fit	95% CI	95% PI
30.125	3.13332	(20.1534, 40.0966)	(15.2316, 45.0184)

Settings, A = 135, B = 75, C = 210, D = 10

Prediction

Fit	SE Fit	95% CI	95% PI
22.875	3.13332	(12.9034, 32.8466)	(7.98161, 37.7684)

Settings, A = 139, B = 80, C = 220, D = 15

Prediction

Fit	SE Fit	95% CI	95% PI
23.625	3.13332	(13.6534, 33.5966)	(8.73161, 38.5184)

Factorial Plots for Cycle Time

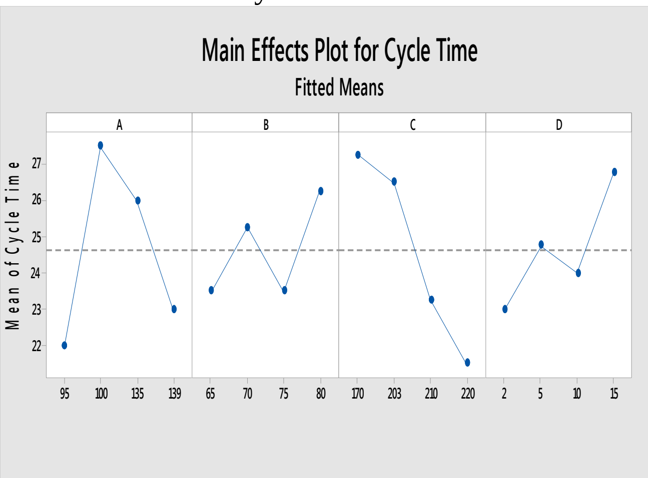

Fig 6.1: Main effects plot for cycle time

Response Optimization: Cycle Time

Parameters

Response	Goal	Lower	Target	Upper	Weight	Importance
Cycle Time	Minimum		18	32	1	1

Solution

Solution	A	B	C	D	Cycle Time Fit	Composite Desirability
1	95	75	220	2	16.125	1

Multiple Response Prediction

Variable	Setting
A	95
B	75
C	220
D	2

Response	Fit	SE Fit	95% CI	95% PI
Cycle Time	16.13	3.13	(6.15, 26.10)	(1.23, 31.02)

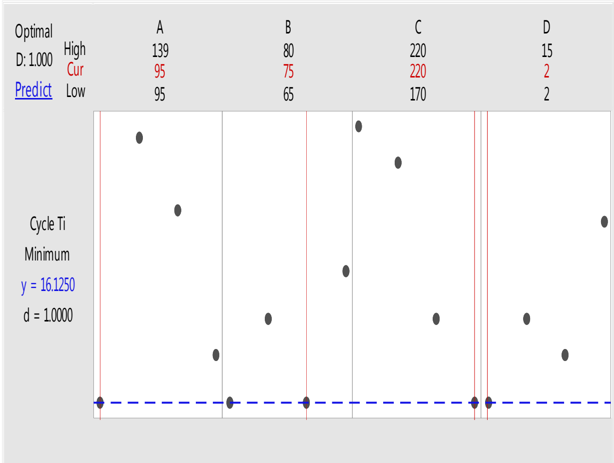

Fig 6.2: Multiple response prediction

The percentage of contribution for all factors is shown in Table 6.1. This results shows that the injection speed contribute the most by 0.651% and this is followed by injection time by 0.557% and injection pressure 0.27% and melt temperature 0.242%. This proves that injection speed and injection time is the most significant parameter contribute is to effects the cycle time in the process while injection pressure and melt temperature only have small effects towards the cycle time.

Effects on Product Parts: While changing the processing parameters frequently some defects are appear on the product parts are shown in fig 7(a) and fig 7(b).

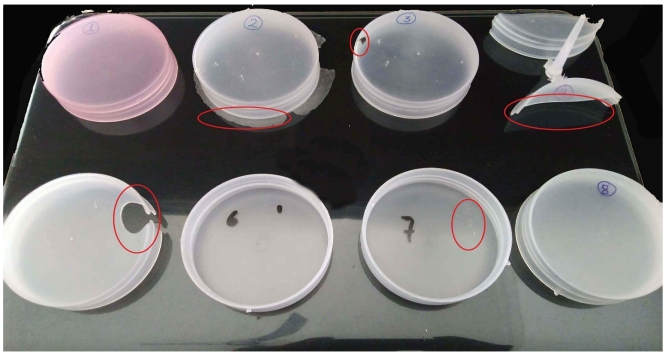

Fig 7(a) final product parts (CIPET Raipur)

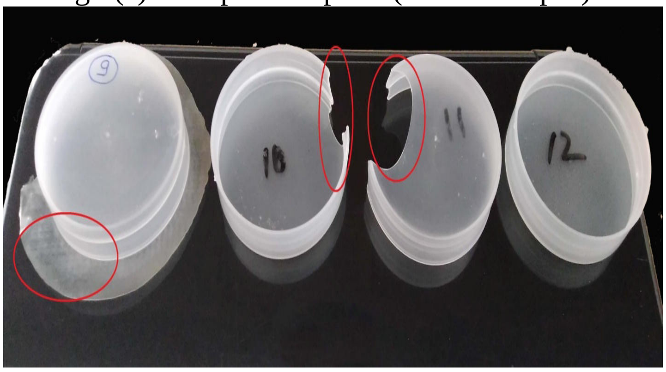

Fig 7(b) Final product parts (CIPET Raipur)

Remedies to Resolve The Defects

Flow lines: Increase the injection speeds and pressure to ensure the cavities are filled evenly. Increase the temperature of the molten plastic or the mold temperature to prevent the plastic from cooling too quickly. Rounds the area of mold where the wall thickness varies to create a uniform flow-path for the molten plastic.

Short shots: Work with a less viscous plastic and increase the mold or melt temperature to enhance flow ability. Adjust the process to account for any gas getting trapped inside the mold and use proper ventilation.

Weld lines: Raising the temperature of the mold or the molten plastic, increase the injection speed, switch to a less viscous plastic or adjust the flow pattern to a single-source flow.

Flash: Increase clamp pressure and confirm that the mold doesn't require cleaning and maintenance. Maintain the melt temperature level of material.

Burn marks: Decrease the injection speeds improve degassing quality and also reducing mold and melt temperatures.

Conclusion: In search of an optimal parameter combination, capable of producing desired quality of the product in a relatively lesser time enhancement in productivity, the Taguchi methodology and ANOVA calculation has been characteristically successful. The work proposes a consolidated optimization approach using Taguchi and ANOVA optimization .The Methodology could serve in minimizing the cycle time by enhancing the production rate and product quality. In injection molding process of Polypropylene material, for optimized the process parameters and cycle time injection speed and filling time is found to be the most significant factor which contributes 0.651 and 0.557 followed by injection pressure by 0.270 and melt temperature 0.242. The results show that, for Polypropylene material the best combination of processing parameters in terms of optimized cycle time = 16.125 sec are injection pressure 95 psi, injection speed 75 mm/s, melt temperature 220 ^{o}C, injection time 2 sec. The influence of all factors has been identified and believed can be a key factor in helping to improve production rate and determining optimum process conditions injection molding parameters.

Cycle Time was reduced by 1.875 sec as against the cycle time prior to experimentation recorded was 18sec and optimized result is 16.125 sec. The percent saving in production was 10.416%, we can reasonably comment that productivity was enhanced by 10.416%.In injection pressure clamping force required and in turns results in reduced power consumption per part weight due to reduction in power requirement for clamping.

Future Scope: Recommendations for future research in the injection molding would include investigating best combination of parameters for optimized cycle time of other plastic materials. Optimum parameters for optimized cycle time of polypropylene material are obtained in this paper, in future optimum parameters for hardness and good surface finish of different materials may also obtain. In this project Taguchi and ANOVA method is used for obtaining the optimum processing parameters combination for a single quality characteristic. Since, the Taguchi does not give any consideration to the relationship between multiple quality characteristics and processing parameters. 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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