Parameter Optimization of Injection Moulding for Polypropylene(PP) Tooth Brush Using Taguchi Method

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Abstract –*Plastic injection moulding is a very challenging process for researchers, designers and manufacturers to produce the components or products at low cost, meeting all the necessary requirements from the customers. In today's plastic age, injection moulding industry is facing a huge global competition. Using a conventional trial-and-error approach for finding out the desired processing parameters conditions for moulding is not good enough to sustain in the global market. It is much difficult to set optimal process parameter levels which may cause defects in articles, such as Short-shots, Flash, Silver-spots & Shrinkage. Many product designing, mould designing aspects along with a large number of process parameters need to be optimized in order to meet customer requirements and expectations regarding quantity, quality and performance of the product at economical price. In this Paper, the application of Taguchi Method on the process parameters of Plastic Injection Moulding of Polypropylene (PP) is presented. The effect of process parameters, such as Injection Pressure, Packing Pressure, Injection Time, Cooling Time, Zone 1 Temperature & Zone 2 Temperature (Barrel Temperatures) on Short Shots and Flash (defects) were investigated using the Orthogonal Array L16 of Taguchi Method for 6 factors at 2 levels each with the response being percent defectives. It was found that Injection Time, Injection Pressure & Zone 1 Temperature had a major effect on the response. After the application of Taguchi Method, the rejection rate dropped down from 10.29% to 5.88%, which is a 42.85% reduction.*

Key Words: Plastic injection moulding, S/N ratio, Taguchi optimization, Process parameters, DOE.

1. INTRODUCTION

Injection moulding is a manufacturing process for producing parts made of plastic. It is a very popular process due to its high production rate as well as its ability to produce very complex geometries at cheaper cost. In this process, the raw material in granular form is fed into the machine by means of a hopper, which pre-heats the material and remove the moisture from the raw material granular. Through the hopper raw material is fed into the barrel . The material is then heated into the barrel with the help of heaters and maintained at required temperatures at a different zone. After this process, the molten polymer is injected into the mould at required pressure from the nozzle. Finally, it is held for given time to cool down and after cooling and solidification, the part is ejected and the process continues.

Injection moulding is widely used for manufacturing an infinite variety of parts, from the smallest components to entire body panels of cars. Parts to be injection moulded must be very carefully designed to facilitate the moulding process usually by an industrial designer or an engineer. The material used for the part, the desired shape & features of the part, the material of the mould and the properties of the moulding machine must all be taken into consideration. There are four factors that affect the quality of moulded parts: part design, mould design, machine performance and processing conditions. The old trial-and-error process is costly and time consuming, thus not suitable for complex manufacturing processes. In order to minimize various defects such as Short-shots, Flash, Silver-spots & Shrinkage in plastic injection moulding, design of experiment, the Taguchi method is applied. In experimental design, there are many variable factors that affect the functional characteristics of the product. Design parameter values that minimize the effect of noise factors on the product's quality are determined. In order to find optimum levels, fractional factorial designs using orthogonal arrays are used. In this way, an optimal set of process parameters conditions can be obtained from very few experiments.

T Kiatcharoenpol et. al. [5], studied the process parameters of Plastic injection moulding and optimize the process parameters to improve quality characteristic of work-piece. The two responses obtained from the experiment are volume shrinkage and total displacement. They concluded that there are three statistically major factors out of seven factors or process parameters. The three significant factors are Melt temperature, packing time and Cooling time. T. Mohan Kumar et. al. [3], investigated the effect of various injection moulding process parameters on the volumetric shrinkage and fill time of a Polypropylene chair bottom cap part. Four process parameters were considered in this research: injection pressure, cooling time, melt temperature and mould temperature. They found that the injection pressure, melt temperature were most significant factors for volumetric shrinkage. Like that for fill time melt temperature and injection pressure were most critical factors for product.

3. TAGUCHI TECHNIQUE

Taguchi technique [2] is an efficient tool for design of high quality manufacturing system, which recommends to use orthogonal array experiments. It is used to optimize the performance characteristics within the combination of design parameters. The signal to noise ratio is a simple quality indicator that researchers and designers can use to evaluate the effects of changing a particular design parameter on performance of the products. Taguchi methods [1] use a special design orthogonal array to study the entire factor with only a small number of experiments

In the product or process design of Taguchi method, there are basically three steps involved:-

(i) *System Design:* selection of a system for a given objective function.
(ii) *Parameter Design:* to find the optimum combinations of the process conditions for improving performance characteristics.
(iii) *Tolerance Design:* determination of tolerance around each parameter level.

Taguchi method uses signal-to-noise (S/N) ratio which reflects both the average and the variation of the quality characteristics. It is a measure of performance aimed at developing products and processes insensitive to noise factors. The standard S/N ratio used is as follows: Larger-the-better, Smaller- the- better, Nominal-the-best . In this study S/N ratio characteristics the smaller-the-better is applied in the analysis which is given in table 4 and can be calculated by using relation.

$S/N = -10 \log_{10}(1/n \, \Sigma \, y_i^2)$

Where y_i is the value of the quality characteristics for the i^{th} trials, n is number of repetitions.

4. EXPERIMENTAL STUDY

A. Materials: Polypropylene(PP) were used as a tough and semi-crystalline polymer produced from the combination of propene (or propylene) monomers. The chemical formula of propylene is $(C_3H_6)_n$. Polypropylene is among the cheapest plastics available today and is one of the top three widely used polymers also. PP has high flexural strength, relatively slippery surface, very resistant to absorbing moisture and good chemical resistance. The general properties of PP are shown in table 1.

Table 1: Properties of Polypropylene

Property	Value
Density (g/cm3)	0.91-0.94
Modulus of elasticity, E (MPa)	1340
Poisson's Ratio, ν	0.392
Specific Heat, Cp (J/kg°C)	3100
Thermal conductivity, K (w/m°C)	0.17

B. Objective Definition: The experimentation objective was to minimize the rejection rate of the product manufactured due to defects like Short-shots, Flash, Silver-spots & Shrinkage. The major defects were found out to be Short-shots and Flash from the manufacturing history. Approximately 10% was the rejection rate in the Production of this product. Figure 1 shows the rejection detail.

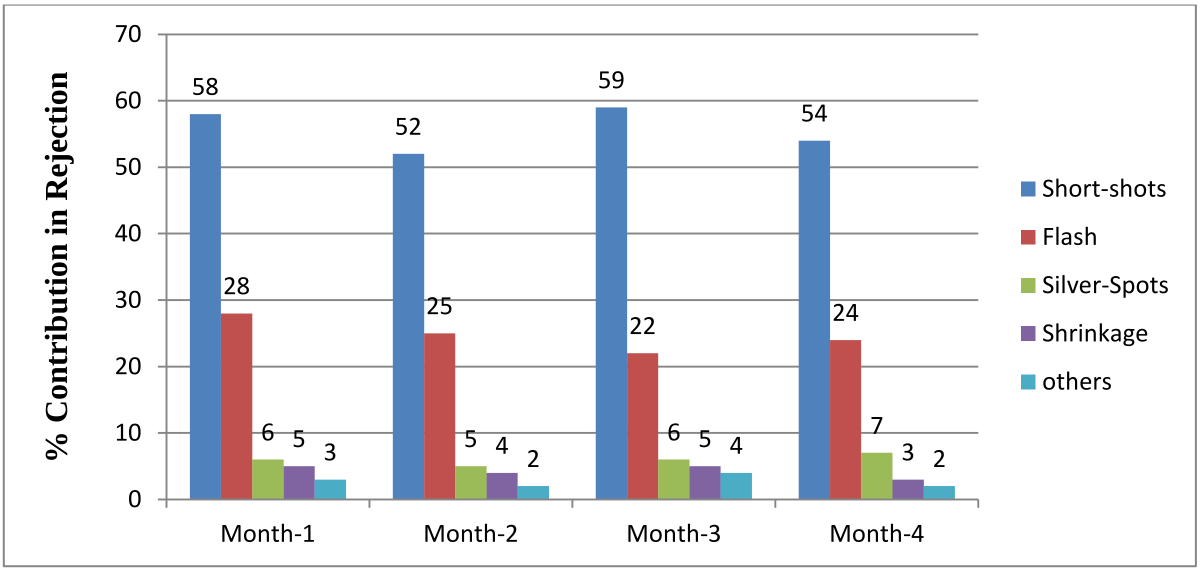

Figure 1: Percentage contribution of rejection

C. Selection of Factors: The experiment was conducted with three basic processing parameters, which play a vital role in Injection Moulding process; Temperature, Time and Pressure.

D. Factor Levels Selection: The process parameters and two different working levels are shown in the Table 2. These levels were selected as per the opinion of the machine expert.

Table 2: Injection Moulding parameters and levels

A. Temperature [°C]	1. Zone 1	High	220
		Low	210
	2. Zone 2	High	205
		Low	195
B. Pressure [bar]	3. Injection	High	55
		Low	50
	4. Packing	High	40
		Low	30
C. Time [sec]	5. Injection	High	8
		Low	6
	6. Cooling	High	10
		Low	8

E. Selection of Orthogonal Arrays (OA): It is important to select accurate orthogonal array and for this task Minitab 17 Statistical Software was used for designing the experiments. In this work, the Orthogonal Arrays (L16) are used to study the six factors at two levels. The 16 different experimental conditions are set as shown in Table 3. Two replicates were performed in each condition and the percentage defectives are measured as responses, as shown in Table 4. The overall experiments are run on 16 experiments.

Table 3: L_{16} Orthogonal Array design for 6 factors at 2 levels

Run No.	Injection Pressure [bar]	Packing Pressure [bar]	Injection Time [sec]	Cooling Time [sec]	Zone 1 Temperature [°C]	Zone 2 Temperature [°C]
1	50	30	6	8	210	195
2	50	30	6	10	210	205
3	50	30	8	8	220	195
4	50	30	8	10	220	205
5	50	40	6	8	220	205
6	50	40	6	10	220	195
7	50	40	8	8	210	205
8	50	40	8	10	210	195
9	55	30	6	8	220	205
10	55	30	6	10	220	195
11	55	30	8	8	210	205
12	55	30	8	10	210	195
13	55	40	6	8	210	195
14	55	40	6	10	210	205
15	55	40	8	8	220	195
16	55	40	8	10	220	205

Table 4: Response of % defectives

Run No.	Injection Pressure [bar]	Packing Pressure [bar]	Injection Time [sec]	Cooling Time [sec]	Zone 1 Temperature [°C]	Zone 2 Temperature [°C]	Run 1	Run 2
1	50	30	6	8	210	195	9.55	10.29
2	50	30	6	10	210	205	13.23	11.76
3	50	30	8	8	220	195	10.29	11.02
4	50	30	8	10	220	205	13.97	15.44
5	50	40	6	8	220	205	8.08	6.61
6	50	40	6	10	220	195	8.82	7.35
7	50	40	8	8	210	205	15.44	13.23
8	50	40	8	10	210	195	16.17	14.70
9	55	30	6	8	220	205	6.61	5.88
10	55	30	6	10	220	195	7.35	7.35
11	55	30	8	8	210	205	11.02	10.29
12	55	30	8	10	210	195	11.76	12.50
13	55	40	6	8	210	195	8.82	9.55
14	55	40	6	10	210	205	8.08	8.82
15	55	40	8	8	220	195	13.23	12.50
16	55	40	8	10	220	205	8.08	11.02

Table 5: Signal-to-Noise ratio for Smaller-the-Better

Level	Injection Pressure, A [MPa]	Packing Pressure, B [MPa]	Injection Time, C [sec]	Cooling Time, D [sec]	Zone 1 Temperature, E [°C]	Zone 2 Temperature, F [°C]

1	-21.04	-20.16	-18.56	-19.87	-21.11	-20.37
2	-19.40	-20.27	-21.87	-20.57	-19.33	-20.07
Delta	1.64	0.11	3.31	0.70	1.78	0.30
Rank	**3**	6	**1**	4	**2**	5

5. RESULTS AND DISCUSSION

Analysing the Result: From the Signal-to-Noise ratio Table 5, it was found that injection time, Zone 1 temperature and injection pressure were the significant factors. From the Main Effect Plots for means & S/N Ratio, the optimum level of all factors were determined. The optimum value for all the factors are as follows and given in Table 5 and S/N ratio response diagram was shown in Figure 2, Figure 3 and Figure 4.

Table 6: Optimum value of factors

Factors	Level	Value
Injection Pressure [bar]	High	55
Packing Pressure [bar]	Low	30
Injection Time [sec]	Low	6
Cooling Time [sec]	Low	8
Zone 1 Temperature [°C]	High	220
Zone 2 Temperature [°C]	High	205

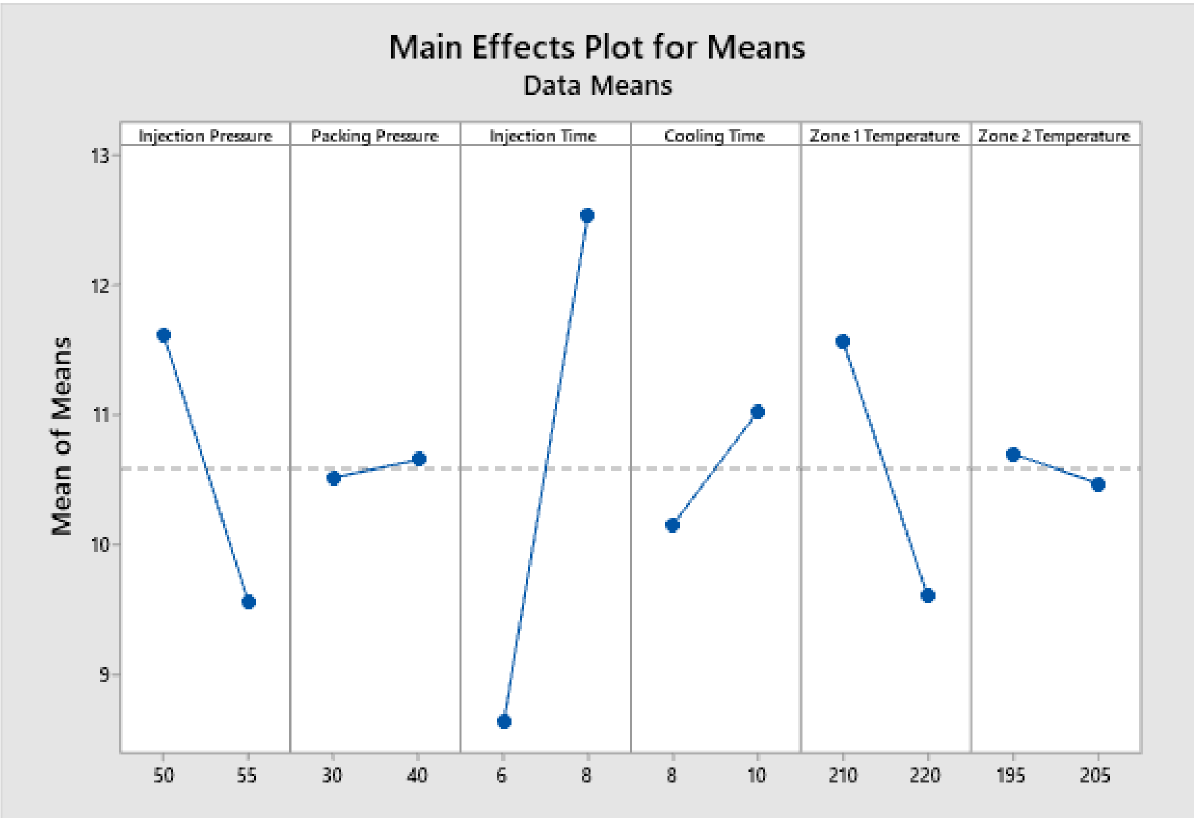

Figure 2: Main Effect Plot for Means

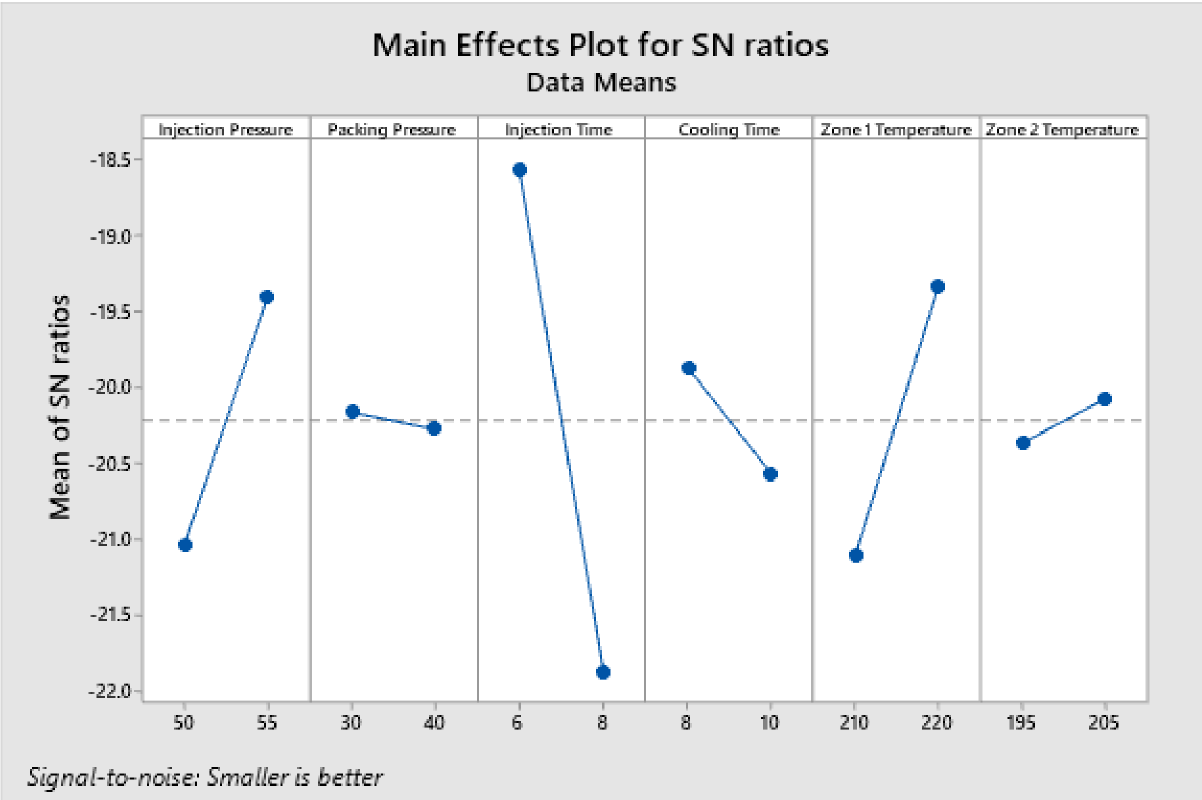

Figure 3: Main Effect Plot for S/N Ratios

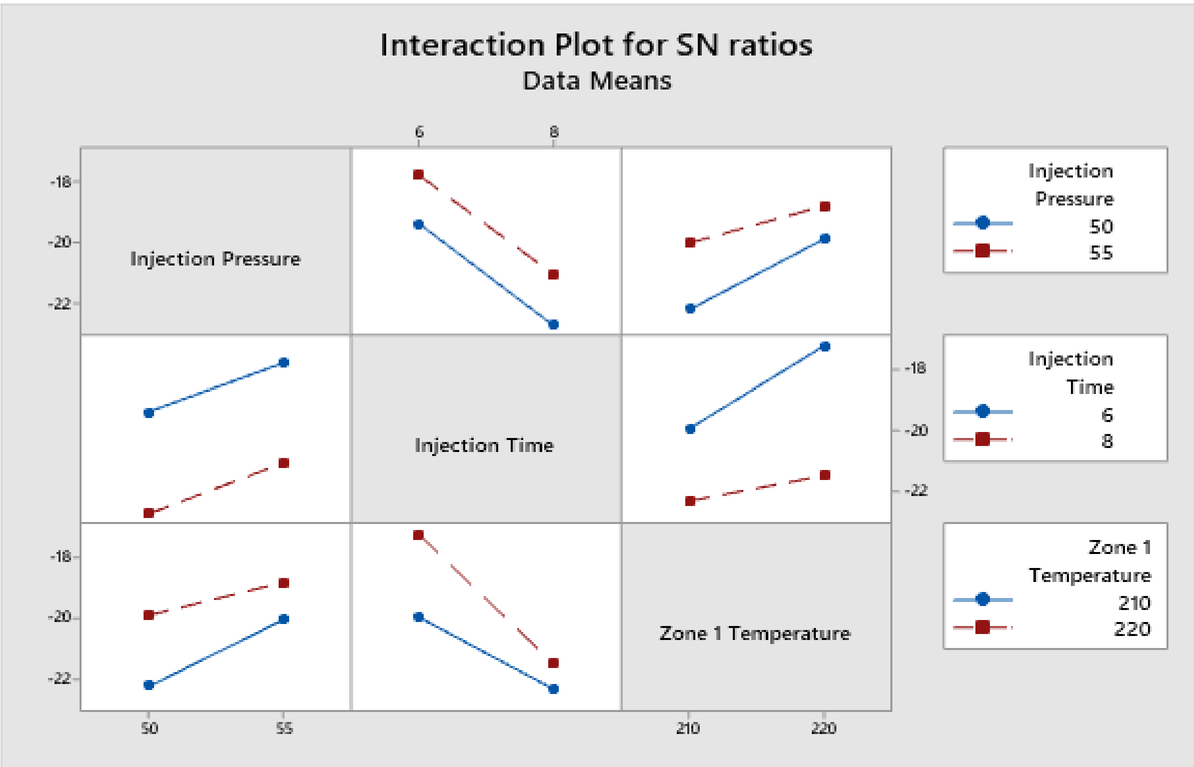

Figure 4: Interaction Effect Plots for S/N Ratio

From the Interaction Effect Plots, it is clear that there is no Interaction in between the factors.

Confirmation Run: The result of the confirmation run for the optimum setting are shown in Table 6. Thus from a rejection rate of 10.29%, optimization of the process with the help of Taguchi Method reduced it to 5.88%.

Hence, reduction in % rejection = (10.29-5.88)/10.29 = 42.85%

Table 7: Confirmation run results

No. of pieces Produced	No. of defective pieces observed	%defectives
68x3 = 204	12	5.88%

6. CONCLUSION

The Signal-to-Noise Ratio table for Smaller-the-Better condition is given in table 5, and the best set of combination parameter can be determined by selecting the level with highest value for each factor. As a result, the optimal process parameter combination for Polypropylene(PP) is A2, B1, C1, D1, E2, F1. The Delta value given in table 5 shows that injection time is the most significant factor affecting the response followed by Zone 1 temperature and injection pressure.

Packing pressure was found to be the least effective factor. From the findings, it can be stated that Taguchi method is a powerful tool used for setting the optimum parameters of the process and it gives break through result.

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