Reducing Shrinkage in Plastic Injection Moulding using Taguchi Method in Tata Magic Head Light

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Abstract: ***Injection moulding has been a challenging process for many plastic components manufacturers and researchers to produce plastics products meeting the requirements at very economical cost. Since there is global competition in injection moulding industry, so using trial and error approach to determine process parameters for injection moulding is no longer hold good enough. Since plastic is widely used polymer due to its high production rate, low cost and capability to produce intricate parts with high precision. It is much difficult to set optimal process parameter levels which may cause defects in articles, such as shrinkage, warpage, line defects. Determining optimal process parameter setting critically influences productivity, quality and cost of production in plastic injection moulding (PIM) industry. In this paper optimal injection moulding condition for minimum shrinkage were determined by the DOE technique of Taguchi methods. The various observation has been taken for material namely Polypropylene (PP).The determination of optimal process parameters were based on S/N ratios.***

Keywords: Injection moulding, DOE, Taguchi optimization.

1. Introduction

Injection moulding represents one of the most important processes in the mass production of manufactured plastic parts with complex geometries. The quality of the injection mouldings depends on the material characteristics, the mould design and the process conditions. Defects in the dimensional stability of the parts result in shrinkage. Severe shinkage lead to deflection of warpage in moulded parts as well as negatively influence the dimensional stability and accuracy of the parts. Many factors including materials selection, part and mould design, as well as injection moulding process parameters can affect shrinkage behaviour in an injection moulded part. The study carried by Chang and Faison [1] reported that more shrinkage occurs across the flow direction than along the flow direction. Chang and Faison studied the shrinkage behavior and optimization of PS, HDPE and ABS parts by using the Taguchi and ANOVA methods. They stated that the mold and melt temperatures along with the holding pressure and the holding time were the most significant factors affecting the shrinkage behavior of the three materials studied. One of the main goals in injection moulding is the improvement of quality of moulded parts besides the reduction of cycle time, and lower production cost. For instant, poor cooling system will give rise to non uniform mould surface temperature and irrational gate location, would lead to differential shrinkage in moulded parts [2,3]. For the effects of processing parameters on shrinkage in POM injection moulded parts, Postawa and Koszkul [4] reported that the clamp pressure and the injection temperature were key parameters.

As in many manufacturing industry meeting required specification means keeping quality under control Quality problems can be material related defects i.e. black specks and splay , process related such as filling related defects i.e. flash and shots packing and cooling related defects i.e., sink marks and voids, and post, mould related defects i.e., warpage , dimensional changes. Vaatainen et al. [5] investigated the effect of the injection moulding parameter on the visual quality of mouldings using the Taguchi method. They focused on the shrinkage with three more quality characteristics: weight, weld line and sink marks.

Factors that affect the quality of moulded parts can be grouped into: part design, mould design, machine performance and processing conditions. The trial-and-error process is costly and time consuming, thus not suitable for complex manufacturing processes. In order to minimize such defects 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 conditions can be obtained from very few experiments [6,7]. This paper attempts to describe the optimization of the injection molding process parameters for optimum shrinkage performance of a plastic head light of Tata Magic which is made from Polypropylene polymer. In this paper the process parameter such as Injection temperature, Injection pressure, Packing pressure and Packing time has been taken to get best combination to optimize the process. Signal-to-noise ratio was used to obtain the optimal set of process parameters.

2. Experimental Studies

2.1 Materials

Polypropylenes were used as an amorphous and a semi crystalline polymer. The general properties of PP are shown in table 1.

Table 1: Properties of Polypropylene

Density(g/cm^3)	0.90-0.91
Melt flow index(g per 10 min)	10.78
Modulus of elasticity(MPa)	4100
Charpy impact toughness(KJ/m^2)	1.4-1.8

The experiment was conducted with four controllable, three level processing parameters: melt temperature, injection pressure, packing pressure, packing time, therefore the L27 orthogonal array was selected for this study. The process parameters and levels are shown in table 2 and the L27 orthogonal array in table 3.

Table 2: The process parameters and levels

S.No	Factors	Level 1	Level 2	Level 3
1	Melt temperature, A (°C)	220	250	280
2	Injection Pressure, B(MPa)	55	65	70
3	Packing Pressure(MPa)	35	45	60
4	Packing time,D(s)	5	8	10

Table 3: The L27 orthogonal array

Deney No	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	1	1	1	2
5	1	2	2	3
6	1	3	3	1
7	1	1	1	3
8	1	2	2	1
9	1	3	3	2
10	2	2	3	1
11	2	3	1	2
12	2	1	2	3
13	2	2	3	2
14	2	3	1	3
15	2	1	2	1
16	2	2	3	3
17	2	3	1	1
18	2	1	2	2
19	3	3	2	1
20	3	1	3	2
21	3	2	1	3
22	3	3	2	2
23	3	1	3	3
24	3	2	1	1
25	3	3	2	3
26	3	1	3	1
27	3	2	1	2

2.2 Shrinkage measurement

Shrinkage is the difference between the size of mold cavity and size of finished part divided by the size of a mold. The relative shrinkage of selected characteristics were calculated with following equation

$$S = (Dm- Dp)/ Dm \times 100\%$$

Where S denotes the shrinkage, Dm denotes the mold dimension and Dp denotes the part dimension. In this study three trial of shrinkage taken and S/N ratio is calculated by average value of the three shrinkage value.

3. Results and Discussion

3.1 Taguchi Method

Taguchi's philosophy is an efficient tool for design of high quality manufacturing system, which has been developed based on orthogonal array experiments, which provide much reduced variance for experiment with optimum setting of process control parameters[8].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.[9,10] Taguchi methods [11] use a special design orthogonal array to study the entire factor with only a small number of experiments[12,13].It introduces an integrated approach that is simple and efficient to find the designs for quality, performance and computational cost[14].

In product or process design of Taguchi method, there are three steps:

i) System design: selection of system for given objective function.
ii) Parameter design: selection of optimum levels of parameter
iii) Tolerance design: determination of tolerance around each parameter level [15].

Taguchi method uses the signal-to-noise (S/N) ratio instead of average. The S/N ratio reflects both the average and the variation of the quality characteristics[6].As discussed by Oktem el at.[16] the S/N ratio is a measure of performance aimed at developing products and processes insensitive to noise factors. The standard S/N ratio used is as follows: Nominal is best (NB), lower the better (LB) and higher the better (HB) [4]. In this study lower value of shrinkage behavior is expected. Thus S/N ratio characteristics the lower – the- better is applied in the analysis which is given in table 4 and can be calculated by using relation.

$$S/N = -10 \operatorname{Log}_{10} (1/n\sum 1/y_i^2)$$

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

Table 4: Shrinkage values and S/N ratio for PP

Melt temperature (ºC)	Injection pressure (MPa)	Packing pressure (MPa)	Packing time (s)	Shrinkage (%) PP			Average Shrinkage (%) PP	S/N (dB) PP
				Trial 1	Trial 2	Trail 3		
220	55	35	5	1.854	1.763	1.712	1.776	-4.988
220	65	45	8	1.532	1.386	1.412	1.443	-3.185
220	70	60	10	1.212	1.132	1.198	1.180	-1.437
220	55	35	8	1.768	1.582	1.698	1.682	-4.516
220	65	45	10	1.622	1.562	1.442	1.542	-3.761
220	70	60	5	1.523	1.368	1.452	1.447	-3.209
220	55	35	10	1.658	1.542	1.764	1.654	-4.370
220	65	45	5	1.452	1.564	1.412	1.476	-3.381
220	70	60	8	1.224	1.383	1.286	1.297	-2.258
250	65	60	5	1.423	1.386	1.328	1.379	-2.791
250	70	35	8	1.743	1.826	1.656	1.741	-4.815
250	55	45	10	1.537	1.368	1.484	1.463	-3.304
250	65	60	8	1.213	1.197	1.126	1.178	-1.422
250	70	35	10	1.433	1.332	1.387	1.384	-2.822
250	55	45	5	1.563	1.351	1.654	1.522	-3.648
250	65	60	10	1.145	1.231	1.198	1.191	-1.518
250	70	35	5	1.573	1.845	1.663	1.693	-4.573
250	55	45	8	1.723	1.642	1.483	1.616	-4.168
280	70	45	5	1.321	1.412	1.289	1.340	-2.542
280	55	60	8	1.543	1.487	1.373	1.467	-3.328
280	65	35	10	1.345	1.294	1.278	1.305	-2.312
280	70	45	8	1.532	1.384	1.576	1.497	-3.504
280	55	60	10	1.213	1.073	1.116	1.134	-1.092
280	65	35	5	1.642	1.735	1.572	1.649	-4.344
280	70	45	10	1.234	1.198	1.342	1.258	-1.993
280	55	60	5	1.473	1.386	1.356	1.405	-2.953
280	65	35	8	1.379	1.287	1.327	1.331	-2.483

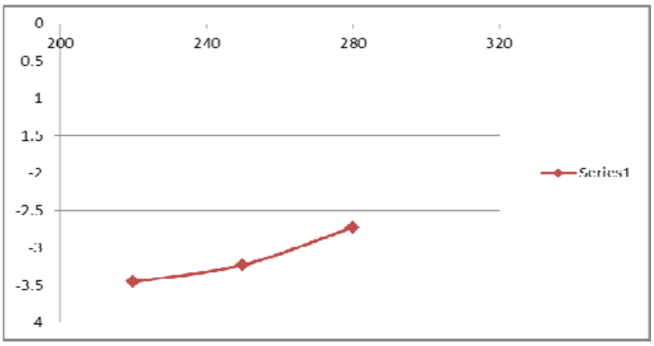
The response table of the S/N ratio is given in table 5, and the best set of combination parameter can be determined by selecting the level with highest value for each factor. As a result, the optimal process parameter combination for PP is A3, B2, C3, D3.

The difference value given in table 5 denotes which factor is the most significant for shrinkage of PP molding. Packing pressure was found most effective factor for PP followed by packing time, injection pressure and melt temperature.

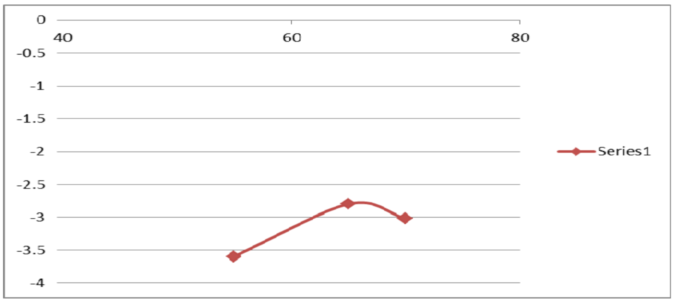
Table 5: The response table for S/N ratio for PP

S. No.	Melt temperature A (ºC)	Injection Pressure B (MPa)	Packing Pressure C (MPa)	Packing time (s)
Level 1	-3.456	-3.596	-3.913	-3.603
Level 2	-3.229	-2.799	-3.276	-3.297
Level 3	-2.727	-3.017	-2.223	-2.512
Difference	-0.729	-0.797	-1.69	-1.091

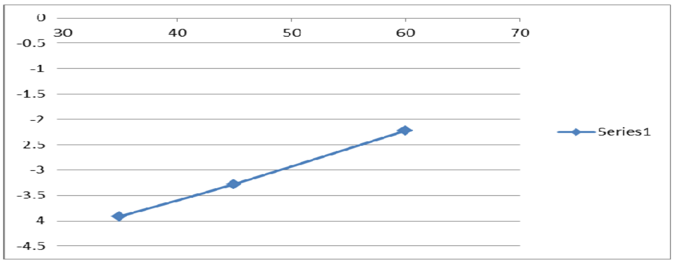
From the given data in table 5 S/N ratio response diagram was drawn shown in fig a, b, c, d. The highest S/N ratio for each factor gave the optimal process condition, which corresponds to melt temperature 280ºC, an injection pressure 65 MPa, packing pressure of 60 MPa and injection time of 10 s.



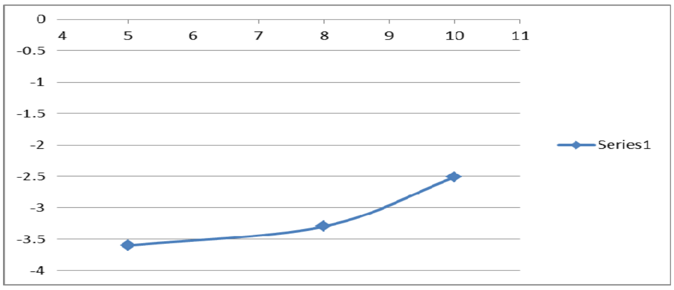
a) S/N ratio V/s Melt temperature(ºC)



b) S/N ratio V/s Injection Pressure



c) S/N ratio V/s Packing pressure



d) S/N ratio V/s Packing time.

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