Taguchi and ANOVA analysis of shrinkage of Injection moulded polypropylene Component

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Abstract— In the present era, competition gets tougher; there is more pressure on manufacturing sectors to improve quality and customer satisfaction while decreasing cost and increasing productivity. These can be achieved by using modern quality management systems and process improvement techniques to reduce the process variability and driven waste within manufacturing process using effective application of statistical tools. Taguchi technique is well known technique to solve industrial problems. In this study, effect of injection molding parameters on the shrinkage in polypropylene (PP) is investigated. The relationship between input and output of the process is studied using Taguchi method and Analysis of Variance (ANOVA) technique. The selected input parameters are melting temperature, injection pressure, packing pressure and packing time. Effect of these parameters on the shrinkage of above mentioned materials is studied using mathematical modelling. The determination of optimal process parameters were based on S/N ratios.

Keywords: Injection moulding, ANOVA, Taguchi analysis, Shrinkage

1. Introduction

Nowadays, competitive market requires producers to produce high quality parts, with lower price in the least possible time. Injection molding is known as an effective process for mass production of plastic parts with complicated forms and high dimensional precision. In this method, high pressure fluid polymer is injected to the cavity with desired form. Next, under high pressure, fluid solidifies. During the process, plastic materials are under high pressure and temperature. Materials are cooled to get desired form. Injection molding process can be divided into four stages: Plasticization, injection, packing and cooling. Although molding process may seem simple, the molded polymers are effected by many machine parameters and process condition.

Incorrect input parameters settings will cause bad quality of surface roughness, decreases dimensional precision, Warpage, unacceptable wastes, increases lead time and cost. Therefore, finding the optimized parameters is highly desirable. In past scientists used trials and error to find good Process conditions but this method is time and cost Consuming. In addition, when there are a large number of Input parameters, these methods can't be used. Nowadays, The model of the process and optimal condition are developed Using analytic methods and heuristic algorithms.

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 sinkmarks.

2 Experimental Studies

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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 parameter: melt temperature, injection pressure, packing pressure, packing time, therefore the L_{27} orthogonal array was selected for this study. The process parameters and levels are shown in table 2 and the L_{27} 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 (ºC)	200	230	260
2	Injection Pressure, B(MPa)	45	55	65
3	Packing Pressure(MPa)	40	55	70
4	Packing time,D(s)	6	10	14

Table 3 The L_{27} 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

$$S = (D_m - D_p)/ D_m \times 100\%$$

Where S denotes the shrinkage, D_m denotes the mold dimension and D_p 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

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].It introduces an integrated approach that is simple and efficient to find the designs for quality, performance and computational cost
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
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. 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 are 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.

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$$S/N = -10 \, Log_{10} \left(1/n \sum 1/y_i^2 \right)$$

Where y_i is the value of the quality characteristics for the ith trials, n is number of repetitions.

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

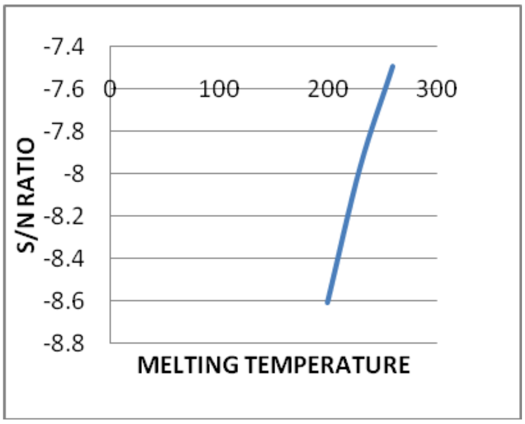
Melt temperature (ºC)	Injection pressure (MPa)	Packing pressure (MPa)	Packing time (s)	Shrinkage (%) PP			Average Shrinkage (%) PP	S/N (dB) PP
				Trial 1	Trial 2	Trai3		
200	45	40	6	3.181	3.036	2.954	3.057	-9.988
200	55	55	10	2.663	2.427	2.472	2.520	-8.028
200	65	70	14	2.145	2.018	2.127	2.096	-6.427
200	45	40	10	3.045	2.745	2.927	2.905	-9.262
200	55	55	14	2.809	3.618	3.427	3.284	-10.328
200	65	70	6	2.645	2.400	2.536	2.527	-8.052
200	45	40	14	2.863	3.590	3.036	3.163	-10.001
200	55	55	6	2.536	2.709	2.472	2.572	-8.205
200	65	70	10	2.163	2.418	2.263	2.281	-7.162
230	55	70	6	2.418	2.427	2.154	2.333	-7.358
230	65	40	10	3.000	3.136	2.863	2.999	-9.539
230	45	55	14	2.672	2.400	2.581	2.551	-8.134
230	55	70	10	2.145	2.118	2.009	2.090	-6.402
230	65	40	14	2.500	2.336	2.427	2.421	-7.679
230	45	55	6	2.709	2.381	2.854	2.648	-8.458
230	55	70	14	2.036	2.172	2.127	2.111	-6.489
230	65	40	6	2.727	2.254	2.872	2.617	-8.356
230	45	55	10	3.336	2.836	2.581	2.917	-9.298
260	65	55	6	3.227	2.463	2.272	2.654	-8.478
260	45	70	10	2.681	2.590	2.409	2.560	-8.164
260	55	40	14	2.363	2.272	2.254	2.296	-7.219
260	65	55	10	2.663	2.418	2.718	2.599	-8.296
260	**55**	**70**	**14**	2.145	1.918	1.990	2.017	-6.094
260	45	40	6	1.927	2.081	2.727	2.245	-7.024
260	65	55	14	2.181	2.118	2.354	2.217	-6.915
260	45	70	6	2.563	2.427	2.445	2.478	-7.882
260	55	40	10	2.418	2.263	2.327	2.336	-7.369

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.

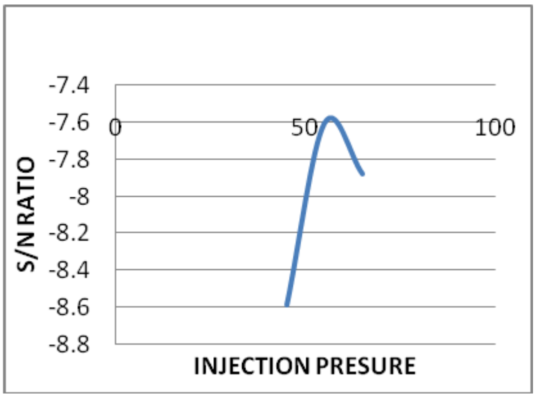
Table 5 The response table for S/N ratio for PP

S.No.	Melt temperature, A (ºC)	Injection Pressure, B (MPa)	Packing Pressure, C (MPa)	Packing time (s)
Level 1	-8.605	-8.586	-8.493	-8.200
Level 2	-7.968	**-7.602**	-8.460	-8.168
Level 3	**-7.493**	-7.878	**-7.114**	**-7.698**
Difference	-1.112	-0.984	-1.379	-0.502
RANK	2	3	1	4

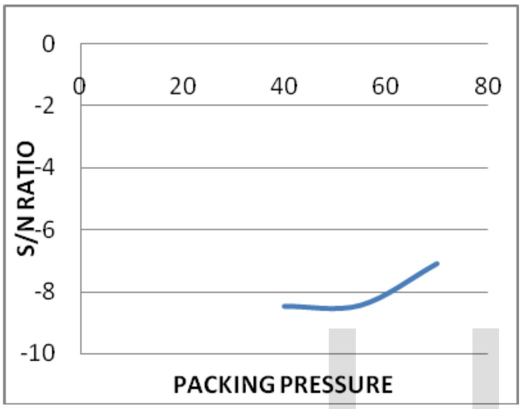
From the given data in table 5 S/N ratio response diagram was drawn shown in fig a,b,c,d. The highest S/N ratio for each factor gave the optimal process condition, which corresponds to melt temperature 260ºC, an injection pressure 55 MPa, packing pressure of 70 MPa and injection time of 14 s.



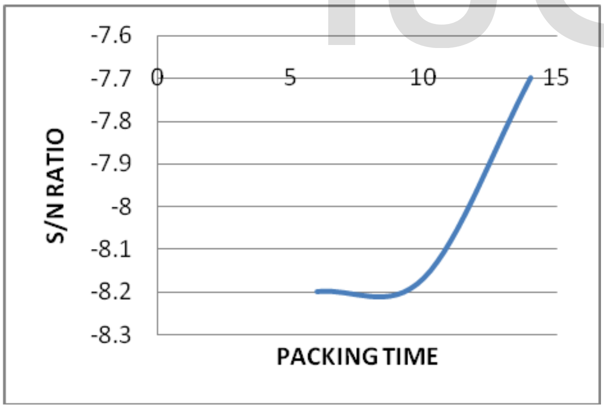
S/N ratio V/s Melt temperature(ºC)



S/N ratio V/s Injection Pressure



S/N ratio V/s Packing pressure



S/N ratio V/s Packing time

ANOVA ANALYSIS

The ANOVA procedure performs *analysis of variance* (ANOVA) for balanced data from a extensive variety of experimental designs. In analysis of variance, a continuous response variable, known as a *dependent variable*, is calculated under experimental conditions recognized by classification variables, known as *independent variables*. The variation in the response is assumed to be due to effects in the classification, with random error accounting for the remaining variation. The ANOVA procedure is one of several procedures available in SAS/STAT software for analysis of variance. The ANOVA procedure is designed to handle balanced data (that is, data with equal numbers of observations for every combination of the classification factors), whereas the GLM procedure can analyze both balanced and unbalanced data. Because PROC ANOVA takes into account the special structure of a balanced design, it is faster and uses less storage than PROC GLM for balanced data.

In ANOVA calculation, the degree of freedom for all factors needs to be obtained. The calculation for degree of freedom is as below:

Total degree of freedom,f

$f_T = N - 1$
$= 27 - 1 = 26$
For Factor A , f_A
$f_A = k_A - 1$
$= 3 - 1 = 2$
Where k_A *is the number of level of factor A*

For Error, $f_E = f_T - (f_A + f_B + f_C + f_D)$

$= 26 - (2+2+2+2) = 18$
Sum of squares,S
$S_T = (Z_{a1}^2 + Z_{a2}^2 + Z_{a3}^2 \ldots\ldots\ldots + Z_{aN}^2) - (Z_{a1} + Z_{a2} + Z_{a3} \ldots\ldots\ldots + Z_{aN})^2/N$
$= (3.057^2 + 2.520^2 + 2.096^2 + \ldots + 2.336^2) - (3.057 + 2.520 + \ldots\ldots + 2.336)^2/27$
$= 175.965 - 173.756 = 2.215$

For Factor A ,
$S_A = \sum(A_1)^2 / k_A + \ldots\ldots \sum(A_3)^2 / k_A - (Z_{a1} + Z_{a2} + Z_{a3} \ldots\ldots\ldots + Z_{aN})^2/N$

$= (3.057 + \ldots\ldots + 2.281)^2/9 + (2.333 + \ldots\ldots + 2.917)^2/9 + (2.654 + \ldots\ldots + 2.336)^2/9 - (3.057 + \ldots + 2.336)^2/27$
$= 66.178 + 57.188 + 50.693 - 173.756 = 0.703$

For Factor B , f_B
$F_B = k_B - 1$
$= 3 - 1 = 2$
Where k_B *is the number of level of factor B*

For Error, $f_E = f_T - (f_A + f_B + f_C + f_D)$
$= 26 - (2+2+2+2) = 18$

For Factor B,
$S_B = \sum(B_1)^2/K_B + \ldots\ldots \sum(B_3)^2/K_B - (Z_{B1} + Z_{B2} + Z_{B3} \ldots\ldots\ldots + Z_{BN})^2/N$
$= (3.057 + \ldots\ldots 2.478)^2/9 + (2.520 + \ldots\ldots + 2.336)^2/9 + (2.096 + \ldots + 2.217)^2/9 - (3.057 + \ldots + 2.336)^2/27$
$= 66.825 + 51.643 + 55.705 - 173.751 = 0.422$

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For Factor C , f_C
$F_C = K_C - 1$
$= 3 - 1 = 2$
Where K_C is the number of level of factor C

For Error, $f_E = f_T - (f_A + f_B + f_C + f_D)$
$= 26 - (2+2+2+2) = 18$

For Factor C
$S_C = \sum(C_1)^2/K_C + \ldots\ldots\sum(C_3)^2/K_C - (Z_{C1} + Z_{C2} + Z_{C3} \ldots\ldots\ldots + Z_N)^2/N$
$= (3.057+\ldots..+2.336)^2/9 + (2.520+\ldots..+2.217)^2 9 + (2.096+\ldots.+2.478)^2 9 - (3.057+\ldots.+2.336)^2/27$
$= 64.208+63.797+46.662-173.751 = 0.916$

For Factor D , f_D
$F_D = K_D - 1$
$= 3 - 1 = 2$

Where K_D is the number of level of factor D

For Error, $f_E = f_T - (f_A + f_B + f_C + f_D)$
$= 26 - (2+2+2+2) = 18$

For Factor D
$S_D = \sum(D_1)^2/K_D + \ldots\ldots\sum(D_3)^2/K_D - (Z_{D1} + Z_{D2} + Z_{D3} \ldots\ldots\ldots + Z_N)^2/N$

$= (3.057+\ldots..+2.478)^2/9 + (2.520+\ldots..+2.336)^2/9 + (2.096+\ldots.+2.217)^2/9 - (3.057+\ldots.+2.336)^2/27$
$= 59.449+59.840+54.493 - 173.751 = 0.131$

For Error, S_e
$S_e = S_T - (S_A + S_B + S_C + S_D)$
$= 2.215 - (0.703+0.422+0.916+0.131)$
$= 0.043$
The values of variances for all factors are then calculated,

For Factor A,
$V_A = \frac{SA}{fA}$
$= 0.703/2 = 0.3515$
For Variance Error , $V_e = \frac{Se}{fe}$
$= 0.043/18 = 0.00238$
F-ratio , F for all factors are calculated as below
For Factor A ,
$F_A = \frac{VA}{Ve} = 0.3515/0.00238 = 147.68$
Percentage Contribution, P_A for Factor A
$P_A = \frac{SA}{ST} X\ 100$
$= (.703/2.215)\ X\ 100 = 31.74\%$

The value of Variance for factor B
$\mathbf{V_B = S_B / f_B}$
$= 0..422/2 = 0.211$
For Variance Error , $V_e = \frac{Se}{fe}$
$= 0.043/18 = 0.00238$
F-ratio , F for all factors are calculated as below
For Factor B ,
$F_B = V_B / V_e = 0.211/.00238 = 88.655$
Percentage Contribution, P_B for Factor B
$P_B = (S_{B/}S_t) \times 100$
$= (0.422/2.215) \times 100 = 19.05\ \%$

The value of Variance for factor C
$\mathbf{V_C = S_C / f_C}$
$= 0.916/2 = 0.458$
For Variance Error , $V_e = \frac{Se}{fe}$
$= .043/18 = 0.00238$
F-ratio , F for all factors are calculated as below
For Factor C ,
$F_C = V_C / V_e = 0.458/0.00238 = 192.43$
Percentage Contribution, P_C for Factor C
$P_C = (S_{C/}S_t) \times 100$
$= (0.916/2.215) \times 100 = 41.35\%$

The value of Variance for factor D
$\mathbf{V_D = S_D / f_D}$
$= .131/2 = .0655$
For Variance Error , $V_e = \frac{Se}{fe}$
$= .043/18 = 0.002388$
F-ratio , F for all factors are calculated as below

For Factor D ,
$F_D = V_D / V_e = .0655/.00238 = 27.52$
Percentage Contribution, P_D for Factor D
$P_D = (S_{D/}S_t) \times 100$
$= (0.131/2.215) \times 100 = 5.91\%$

Factors	F	S	V	F-ratio	P%	RANK
Melt temperature, A (ºC)	2	0.703	0.351	147.68	31.74	2
Injection Pressure , B (MPa)	2	0.422	0.211	88.655	19.05	3
Packing Pressure,C (MPa)	2	0.916	0.458	192.43	41.35	1
Packing time D (s)	2	0.131	0.065	27.52	5.91	4
Pooled Error	18	0.043	0.043		1.95	
Total	26	2.215	1.129		100	

Table 6ANOVA Table

Hence From the table it is clearly mentioned that the Parameters we found in taguchi analysis is also accepted here.

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The ANOVA table is shown in Table 9, giving the percentage contribution and most significant factor contributing to the shrinking of PP mold.

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