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Parametric Optimization of Metal Injection Moulding Process Using Taguchi Method

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Abstract: In this study, the Taguchi method is used to find the optimal moulding parameters for the metal injection moulding (MIM) feedstocks. Parameters optimised are injection temperature (factor A), mould temperature (factor B), injection pressure (factor C) and flow rate (factor D). Feedstocks used were water atomised stainless steel powder with a solid loading of 62 %Vol and the multicomponent binder consisting PEG, PMMA and strearic acid. Green defects and green density were considered as quality characteristics (response) and optimised by using Taguchi's L81 (3^{40}) orthogonal array. Green defects evaluated using parameter design for discrete data technique while green densities were measured according to the MPIF standard 42. The signal-to-noise (S/N) ratio and analysis of variance (ANOVA) are employed to investigate the quality characteristics. The analysis results show that the mould temperature (factor B) is the most significant factor affecting the quality characteristic. The optimal conditions for the green defects and green density are $A_1B_2C_0D_1$ and $A_2B_2C_1D_0$ respectively. The influences of the two-factor interactions and three-factor interactions cannot be neglected.

Keywords: Metal injection moulding, Taguchi method, ANOVA, green defect, green density

1. Introduction

Metal injection moulding (MIM) is known to be very attractive and promising for the mass production of small, complex and near net shape product. This technology consists of four major steps namely mixing, injection, debinding and sintering. Metal powders were initially mixed with a small portion of binder to form the feedstocks. The product is then injection moulded as plastic injection moulding before undergoing the debinding process. Sintering is carried out to obtain the higher mechanical properties. Every processing step will influence the dimension, tolerance and mechanical properties of the MIM parts. Hence, to obtain the high-quality characteristics of products, appropriate selection of the material, binders as well as the optimisation of each of the processing parameter are needed.

The most common optimisation technique employed in the MIM industry practice is the trial and improvement method. This method is very time consuming and costly as much experiment needs to be carried out. To date, researchers in MIM optimise the MIM processing parameter using classical Design of Experiment (DOE) technique and numerical modelling. The systematic application of computer technology produces more satisfactory results. In this work, the Taguchi method, which is well-recognised optimisation tools in plastic injection moulding and material removal process, is applied to optimise the moulding parameter. The recent researchers who employed the Taguchi method in MIM optimisation work are Amin et al. [1], Mustafa et al. [2] and Md Radzi et al. [3].

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Taguchi Method is deemed to be one of the most powerful tool use for process optimisation. When compared to traditional optimisation method, the Taguchi method is more economical because of its low number of experiments. To improve product quality, this method uses a systematic approach to the design and analysis of experiments [4]. According to Taguchi, quality is referred to as the losses of the product [5], [6]. Most of these losses are resulting from variation (noise) of the process. Thus, Taguchi parameter design focus on meeting the mean target and reducing the variation. To achieve this, two essential tools namely orthogonal arrays (OA) and signal to noise (S/N) ratio are used. The orthogonal array is a balanced matrix which can investigate many parameters whereas the S/N ratio is a quality characteristic indicator. Ghani et al. [5] and Park [6] commented that the S/N ratio is chosen as the variation indicator because the mean target will decrease when the standard deviation decreases. The three common categories S/N characteristic are [7]:

the higher the better characteristic:

$$S/N = -10 \log \frac{1}{n} \left(\sum \frac{1}{y^2} \right) \tag{1}$$

the smaller the better characteristic:

$$S/N = -10 \log \frac{1}{n} \left(\sum y^2 \right) \tag{2}$$

and the nominal the better characteristic:

$$S/N = -10 \log \frac{\bar{y}}{s_y^2} \tag{3}$$

where n is the number of observation s, y is the observed data, and the $\bar{y}$ is the average of observed data and s_y^2 is the variance of y. The quality characteristic of a study will decide the selection of S/N categories. For example, to optimise the hardness of a material, we choose the higher the better characteristic.

From the literature survey [1], [2], [3], [8], it is noted that most of the researchers did not consider the interaction between the factors when employing the Taguchi optimisation technique. Thus, this study aims to investigate the influences of the factor interaction using Taguchi method and analysis of variance (ANOVA). All interactions of process parameter were considered and accommodate into the L81 (3^{40}) array. The contributions of each of the process parameter to the quality characteristics are determined. The optimal conditions of the green defects and the green density are also identified.

2. Experimental Procedures

Water atomised 316L stainless steel powder with particle size D_{50} = 10μm and spherical shape was used in this study. The solid loading is 62% Vol with binder used consisted of Polyethylene glycol (PEG) (73% wt), Polymethyl methacrylate (PMMA) (25% wt) and stearic acid (2% wt).

The feedstocks were prepared by mixing all the materials in a z blade mixer for 1 hour and 35 minutes at 70°C. The mixture is then granulated into pallet form through a crushing machine. The standardise tensile-test specimen for the testing of polymer materials (ISO 3167), 80 mm length, 20 mm width and 4 mm thickness, were injection moulded using Battenfeld BA 250CDC injection moulding machine.

The selected injection moulding process parameters along with their levels are given in Table 1. These levels of the process parameters were selected through the prior preliminary run and literature [9]. Each parameter had three level of degree of freedom and all interactions between the parameters were considered in this study.

Table 1 - Injection parameter for three levels of Taguchi Design

Injection Parameters	**Symbol**	**Level**		
		0	**1**	**2**
Injection temperature (°C)	A	140	150	160
Mould temperature (°C)	B	60	65	70
Injection pressure (bar)	C	550	650	750
Flow rate (cm^3/s)	D	10	15	20

Table 2 - Rating for green defects [9]

Physical defects	Score
Flashing	0.5
Excess flashing	1
Binder separations	1.5
Ejector pin mark	1.5
Weld lines	1.5
Flows mark	1.5
Wrinkle	2
Jetting	2
Chipping at gate	2
Cracking	3
Deflection	3
Green broken during ejection	3
Incomplete filling	3

In order to select the appropriate orthogonal array for the experiment, the total degrees of freedom need to be known. The number of treatment conditions is equal to the number of rows in the orthogonal array and must be equal to or greater than the degree of freedom [10]. The degrees of freedom defined as the number of comparisons between the process parameter that needs to be made. The degrees of freedom for each factor can be obtained by the subtraction number of level and their number of constraints. Generally, the number of constraints for each factor is equal to 1. For example, factor A will have the degrees of freedom equal to 2. The degree of freedom associated with the interaction between the parameter is given by the product of the degrees of freedom. It is easy to identify the total degrees of freedom by taking the sum of the degrees of freedom for each factor. The orthogonal array L81 (3^{40}) was chosen as the total degrees of freedom for this study are 80. It is capable of checking the all possible interactions occur between the parameters. The three level of each factor is representing by a '0' or a '1' or a '2' in the array. Eighty-one treatment condition or runs with five repetitions was conducted. The physical defects of the green part were evaluated using the rating as shown in Table 2 while the green density was determined by Archimedes immersion method according to MPIF standard 42.

3. Results and Discussion

3.1 Green Defects Optimisation

Taguchi recommends analysing the mean S/N ratio using a conceptual approach that involves graphing the effects and visually identifying the factor that appear to be significant, without using ANOVA, thus making the analysis simple [6]. As mentioned earlier, there are three categories of quality characteristics, i.e. the-lower-the-better, the-higher-the-better and the-nominal-the-better. The-lower-the-better is chosen to obtain the optimal condition for green defects. Regardless of the categories chosen, the higher S/N ratio for the factor level will be the optimal condition for the factor. The mean S/N ratio for the green defects can be computed through Equation (2).

The average S/N response table and the S/N ratio for smaller-the-better for the green defects are shown in Table 3 and Table 4, respectively. Results shown in Table 3 and Fig.1 reveal that mould temperature (factor B) is a significant factor. The observation is consistent with the study done by Wahi et al. [11]. The range of the S/N ratio for the rest factors shown little variations and consider give a moderate effect or less significant to green defects. The mould temperature, 70°C (B_2) appears to be the best choice of getting greater S/N value. The optimal condition of injection temperature (factor A), injection pressure (factor C) and flow rate (factor D) need to be computed through interactions AB, BD and CD as all of these six factors shown small different in S/N value. Park [6] has recommended using the two ways table in finding the optimal condition of interactions. Two ways table of for AB, BD and CD are tabulated in Table 5, and the results show A_1B_2, B_2D_1 and C_0D_1 are optimal conditions.

By evaluating the optimal conditions for B, AB, BD and CD, the overall optimal condition for green defects is $A_1B_2C_0D_1$. The estimated S/N ratio for optimal conditions can be computed using the optimal level for the main effect. Combination $A_1B_2C_0D_1$ is matched with run 47 in Table 4 which gives the S/N value of -9.93436. The estimated S/N value obtained by considering the factor B, D, BD as main effects give the value of -9.8793. Since the difference of estimated S/N value and experiment run value is minimal, the confirmation run is not required. The optimal condition for green defects is injection temperature: 150°C, mould temperature: 70°C, injection pressure: 550 are and flow rate: 15cm^3/s. Analysis of variance (ANOVA) is then performed to investigate the significance and the contribution of the parameter to green defects. Statically, there is a tool called F test to see the significance of parameters. Usually, when $F > 4$, it means the change of the process parameter has a significant effect on the quality characteristic [6], [7]. The contribution (%) of each factor to green defects may compute from ratio of the sum of square to the total sum of square deviation.

The results from Table 6 show the mould temperature (factor B) (12.53%) is the most significant factor to the green defects. The optimal condition for mould temperature is 70 °C. When experimenting, it was noted that the cracks and uneven moulding were observed at the moulding temperature of 60 °C and 65 °C. Low moulding temperature will induce internal stress which will result in crack [12], [13]. Injection temperature (factor A) and injection pressure (factor C) which has fewer amounts of the sum of square were polled as an error. It indicates the change of this parameter within the test range will not bring a severe effect to the parts. The optimal condition for injection pressure was found to be 550 bars as binder separations tend to occur at high pressure. Engström [14] and Wahi et al. [11] have reported a high injection pressure would lower the viscosity of the binders and cause the binder separations. Overall, the ANOVA analysis results are in good agreement with the Taguchi technique where D, BD and CD have a moderate effect on the green defects. The three-factor and four-factor interactions have the significant contribution to the green defects, but it can be ignored in the optimisation as the low value of F indicates poor significant of the factor. The overall ANOVA results agree with the observation from Taguchi optimisation.

Table 3 - S/N response table for green defects

Factor	Mean S/N Ratio Level 0	Mean S/N Ratio Level 1	Mean S/N Ratio Level 2	Range
A	-11.7795	-11.8749	-11.5291	0.3458
B	-12.4449	-11.6213	-11.1174	1.3275
C	-11.4160	-11.8460	-11.9216	0.5056
D	-11.4458	-11.6127	-12.1250	0.6792
AB	-11.5472	-11.6155	-12.0208	0.4736
AC	-11.4768	-11.9298	-11.7769	0.4530
AD	-11.5777	-11.7849	-11.8210	0.2434
BC	-11.7055	-11.9077	-11.5704	0.3374
BD	-11.4118	-11.8479	-11.9239	0.5121
CD	-11.6937	-11.5259	-11.9640	0.4381
ABC	-11.6410	-11.6071	-11.9355	0.3284
ABD	-11.7159	-11.7163	-11.7514	0.0355
BCD	-11.8780	-11.6018	-11.7038	0.2762
ACD	-11.5200	-11.7171	-11.9465	0.4264
ABCD	-11.8259	-11.7467	-11.6110	0.2149

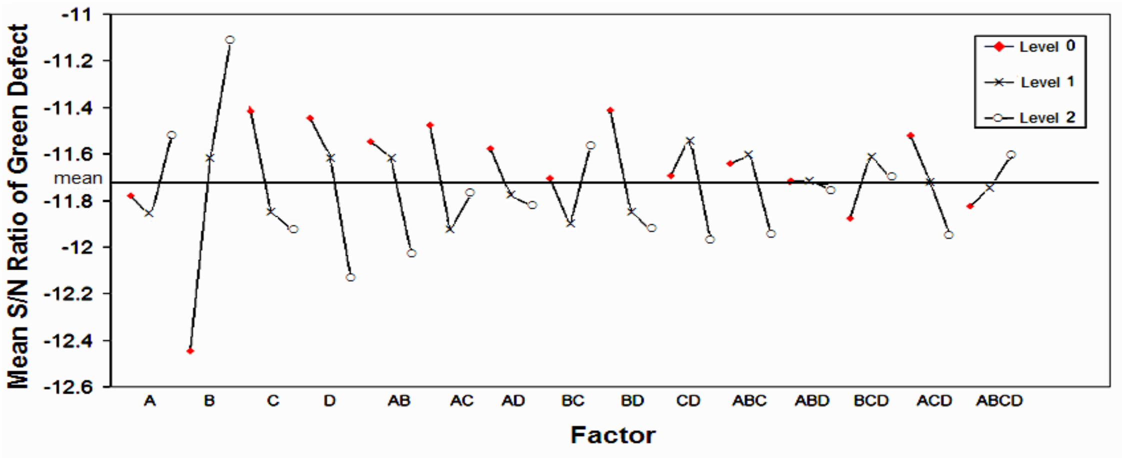

Fig. 1 - The smaller the better S/N graph for green defects

Table 4 - Experiment results for green defects and their corresponding S/N ratio

Run	Factor				Mean Score	S/N ratio	Run	Factor				Mean Score	S/N ratio
	A	B	C	D				A	B	C	D		
1	0	0	0	0	3.1	-10.1072	42	1	1	1	2	5.0	-13.9794
2	0	0	0	1	3.2	-10.4139	43	1	1	2	0	3.7	-11.8041
3	0	0	0	2	4.1	-12.266	44	1	1	2	1	4.0	-12.2272
4	0	0	1	0	3.8	-12.2789	45	1	1	2	2	5.0	-13.9794
5	0	0	1	1	3.6	-11.959	46	1	2	0	0	3.7	-11.6879
6	0	0	1	2	4.4	-13.3646	47	1	2	0	1	3.1	-9.93436
7	0	0	2	0	3.2	-10.1703	48	1	2	0	2	3.6	-11.4922
8	0	0	2	1	5.2	-14.5332	49	1	2	1	0	3.2	-10.4532
9	0	0	2	2	4.9	-14.1246	50	1	2	1	1	2.3	-7.59668
10	0	1	0	0	2.9	-10.3141	51	1	2	1	2	2.9	-9.42008
11	0	1	0	1	4.0	-12.1484	52	1	2	2	0	3.8	-11.6137
12	0	1	0	2	4.0	-12.6245	53	1	2	2	1	3.8	-11.8752
13	0	1	1	0	4.7	-13.6829	54	1	2	2	2	3.7	-11.8893
14	0	1	1	1	3.5	-11.1227	55	2	0	0	0	4.2	-12.6007
15	0	1	1	2	3.2	-10.4922	56	2	0	0	1	3.5	-11.1893
16	0	1	2	0	2.5	-8.22822	57	2	0	0	2	4.2	-12.6007
17	0	1	2	1	3.9	-12.5888	58	2	0	1	0	4.0	-12.1219
18	0	1	2	2	3.7	-11.8327	59	2	0	1	1	5.4	-14.7567
19	0	2	0	0	2.3	-7.9588	60	2	0	1	2	4.0	-12.0683
20	0	2	0	1	2.6	-9.34498	61	2	0	2	0	4.3	-12.7989
21	0	2	0	2	4.7	-13.5122	62	2	0	2	1	3.6	-11.3354
22	0	2	1	0	5.1	-14.2406	63	2	0	2	2	5.0	-14.0312
23	0	2	1	1	3.7	-11.6286	64	2	1	0	0	3.4	-10.8279
24	0	2	1	2	3.9	-11.9451	65	2	1	0	1	3.4	-10.7555
25	0	2	2	0	4.5	-13.7931	66	2	1	0	2	3.3	-10.55
26	0	2	2	1	3.7	-12.266	67	2	1	1	0	3.5	-10.9517
27	0	2	2	2	3.4	-11.1059	68	2	1	1	1	3.0	-9.63788
28	1	0	0	0	3.6	-12.2789	69	2	1	1	2	3.7	-11.5381
29	1	0	0	1	4.1	-12.5888	70	2	1	2	0	3.9	-11.8893
30	1	0	0	2	5.3	-14.7494	71	2	1	2	1	3.7	-11.4457
31	1	0	1	0	4.2	-12.6007	72	2	1	2	2	3.7	-11.7754
32	1	0	1	1	4.4	-13.2634	73	2	2	0	0	3.1	-9.97823
33	1	0	1	2	4.6	-13.8917	74	2	2	0	1	3.6	-11.2385
34	1	0	2	0	2.6	-8.63323	75	2	2	0	2	3.4	-10.6819
35	1	0	2	1	4.2	-12.8556	76	2	2	1	0	4.6	-13.3646
36	1	0	2	2	4.0	-12.4304	77	2	2	1	1	3.6	-11.1727
37	1	1	0	0	4.7	-13.6267	78	2	2	1	2	2.9	-9.31966
38	1	1	0	1	3.6	-11.5229	79	2	2	2	0	3.2	-10.2938
39	1	1	0	2	3.6	-11.2385	80	2	2	2	1	3.9	-11.8893
40	1	1	1	0	3.3	-10.7372	81	2	2	2	2	3.3	-10.4727
41	1	1	1	1	4.0	-12.2531							

Table 5 - Two-way table for green defects

	A_0	A_1	A_2
B_0	-12.1353	-12.588	-12.6115
B_1	-11.4483	-12.3743	-11.0413
B_2	-11.755	-10.6625	-10.9346

	B_0	B_1	B_2
D_0	-11.5101	-11.3402	-11.4871
D_1	-12.5439	-11.5225	-10.7718
D_2	-13.2808	-12.0011	-11.0932

	C_0	C_1	C_2
D_0	-11.0423	-12.2702	-11.025
D_1	-11.0152	-11.4879	-12.3351
D_2	-12.1906	-11.7799	-12.4046

Table 6 - ANOVA table for green defects

Factor		Sum of Square	Degree of freedom	Variance	F	Significant	Contribution (%)
A	Polled	15.504	2				0.89
B		218.266	2	109.133	8.92	Strong	12.53
C	Polled	36.141	2				2.07
D		60.886	2	30.443	2.49	Moderate	3.49
AB		124.167	4	31.042	2.54	Moderate	7.13
AC		76.138	4	19.035	1.56	Weak	4.37
AD	Polled	53.765	4				3.09
BC	Polled	41.397	4				2.38
BD		106.218	4	26.554	2.17	Moderate	6.10
CD		123.770	4	30.943	2.53	Moderate	7.10
ABC		214.249	8	26.781	2.19	Moderate	12.30
ABD		74.154	8	9.269	0.76	Weak	4.26
BCD		154.925	8	19.366	1.58	Weak	8.89
ACD		181.406	8	22.676	1.85	Weak	10.41
ABCD		261.495	16	16.343	1.34	Weak	15.01
(Error)		146.8068	12	12.2339			8.43

3.2 Green Density Optimisation

The experiments results of green density are tabulated in Tables 7 and 8. Table 7 and Fig. 2 show the injection temperature (factor A), and mould temperatures (factor B) are the most significant factor to the green density. The level 2 of these factors are found to be the optimal condition. Also, Table 7 shows the rest of the factors except factors C, ACD and ABC showed a relatively small S/N value and considered as less significant factors. The optimal condition for injection pressure (factor C) and flow rate (factor D) can be obtained via three-factor interactions. Three-way table which tabulates in Table 9 was prepared to find the optimal condition. The result shows $A_1B_2C_2$ the $A_2C_1D_0$ is the best combination to obtain the higher S/N value. However, factors A and C have shown two different optimal conditions. Park [6] suggested optimal level for single factor is given priority in finding the optimal condition if a factor does have more than one optimal condition. Therefore, the optimal condition for green density can be concluding as $A_2B_2C_1D_0$.

The optimal condition found matches with the run 76 in Table 7. The estimated S/N value for the optimal condition for green density by considering factor A and factor B as the main effect is 14.38921. No confirmation run is required as S/N value of run 76 indicate tiny difference with the estimated value. The optimal conditions for green defects are given by injection temperature: 160°C, mould temperature: 70°C, injection pressure: 650 bar and flow rate: 10cm^3/s.

Table 7 - S/N response table for green density

Factor	Mean S/N Ratio Level			Range
	0	1	2	
A	14.2559	14.3359	14.3389	0.0830
B	14.2949	14.2751	14.3605	0.0854
C	14.2978	14.3196	14.3132	0.0218
D	14.3030	14.3136	14.3140	0.0110
AB	14.3126	14.3053	14.3127	0.0075
AC	14.3066	14.3076	14.3164	0.0098
AD	14.3022	14.3175	14.3109	0.0152
BC	14.3184	14.3136	14.2986	0.0198
BD	14.3150	14.3113	14.3043	0.0107
CD	14.3037	14.3152	14.3118	0.0115
ABC	14.3155	14.2975	14.3176	0.0201
ABD	14.3121	14.3072	14.3113	0.0049
BCD	14.3131	14.3104	14.3070	0.0061
ACD	14.3203	14.3133	14.2970	0.0233
ABCD	14.3113	14.3114	14.3078	0.0036

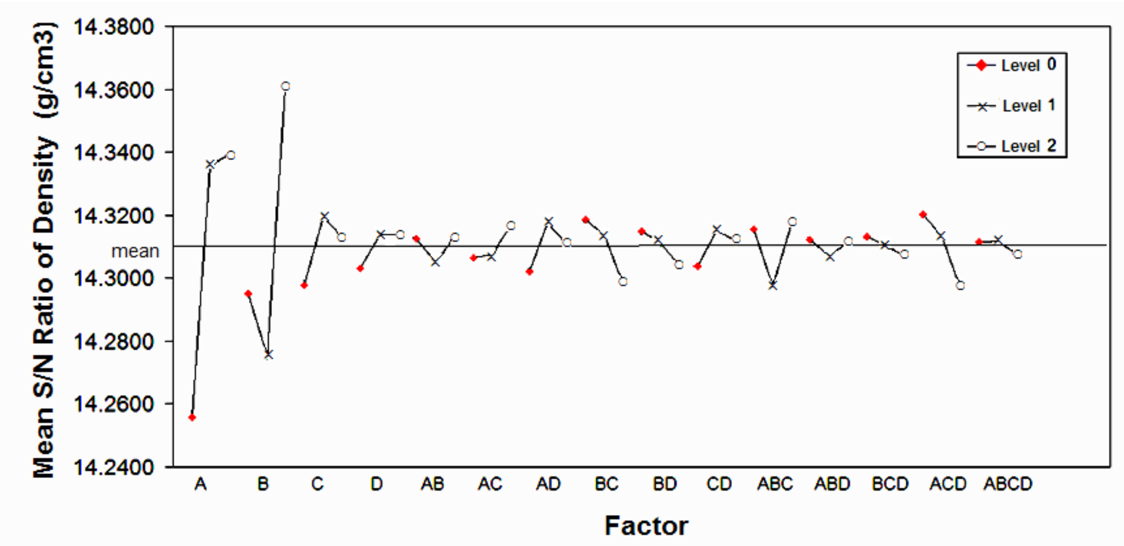

Fig. 2 - The higher-the-better S/N graph for green density

ANOVA result for the green density shown in Table 10 appears injection temperature (factor A), and mould temperature (factor B) are the significant factors. The analysis results agree with the work done by Wahi et al. [11], Kahirur Rijal et al. [9] and Amin et al. [8] These two factors contribute the total of 37.12% to the green density. High injection temperature and higher mould temperature can increase the flowability of the feedstock which allows more particles to fill the mould cavity [8], [11]. On the other hand, Table 10 also display that injection pressure (factor C) and flow rate (factor D) are less significant to the green density. Changing the injection pressure will have only a small effect on green density. This statement is supported by German’s observation [12].

Moreover, analysis results show most of the two-factor interactions except interaction between mould temperature with injection pressure (BC) can be neglected as their sum of square are very low. Ibrahim et al. [15] also concluded that the interaction between mould temperature with injection pressure is the significant factor. Interactions between three parameters, ABC (13.95%) and ACD (10.14%) give moderate effect to the green density. This observation is consistent with the Taguchi analysis. Four-factor interactions are found to be not significant to the green density. The overall results are close to the Taguchi optimisation that had performed.

Table 8 - Experiment results for green density and their corresponding S/N ratio

Run	Factor				Mean density	S/N ratio	Run	Factor				Mean density	S/N ratio
	A	B	C	D				A	B	C	D		
1	0	0	0	0	5.194	14.3090	42	1	1	1	2	5.188	14.3001
2	0	0	0	1	5.189	14.3009	43	1	1	2	0	5.185	14.2939
3	0	0	0	2	5.117	14.1796	44	1	1	2	1	5.179	14.2851
4	0	0	1	0	5.084	14.1233	45	1	1	2	2	5.177	14.2807
5	0	0	1	1	5.159	14.2512	46	1	2	0	0	5.190	14.3022
6	0	0	1	2	5.155	14.2429	47	1	2	0	1	5.197	14.3146
7	0	0	2	0	5.178	14.2823	48	1	2	0	2	5.266	14.4291
8	0	0	2	1	5.136	14.2108	49	1	2	1	0	5.275	14.4441
9	0	0	2	2	5.195	14.3086	50	1	2	1	1	5.267	14.4294
10	0	1	0	0	5.138	14.2143	51	1	2	1	2	5.227	14.3638
11	0	1	0	1	5.240	14.3831	52	1	2	2	0	5.279	14.4517
12	0	1	0	2	5.109	14.1669	53	1	2	2	1	5.269	14.4347
13	0	1	1	0	5.132	14.2046	54	1	2	2	2	5.325	14.5255
14	0	1	1	1	5.121	14.1854	55	2	0	0	0	5.177	14.2816
15	0	1	1	2	5.200	14.3196	56	2	0	0	1	5.207	14.3304
16	0	1	2	0	5.087	14.1295	57	2	0	0	2	5.221	14.3545
17	0	1	2	1	5.109	14.1613	58	2	0	1	0	5.273	14.4405
18	0	1	2	2	5.090	14.1337	59	2	0	1	1	5.264	14.4258
19	0	2	0	0	5.138	14.2126	60	2	0	1	2	5.225	14.3604
20	0	2	0	1	5.090	14.1331	61	2	0	2	0	5.150	14.2340
21	0	2	0	2	5.146	14.2264	62	2	0	2	1	5.156	14.2452
22	0	2	1	0	5.117	14.1796	63	2	0	2	2	5.138	14.2156
23	0	2	1	1	5.246	14.3957	64	2	1	0	0	5.204	14.3256
24	0	2	1	2	5.272	14.4385	65	2	1	0	1	5.209	14.3339
25	0	2	2	0	5.272	14.4395	66	2	1	0	2	5.222	14.3556
26	0	2	2	1	5.275	14.4426	67	2	1	1	0	5.193	14.3089
27	0	2	2	2	5.208	14.3332	68	2	1	1	1	5.201	14.3203
28	1	0	0	0	5.200	14.3203	69	2	1	1	2	5.217	14.3481
29	1	0	0	1	5.191	14.3044	70	2	1	2	0	5.212	14.3402
30	1	0	0	2	5.195	14.3096	71	2	1	2	1	5.237	14.3811
31	1	0	1	0	5.211	14.3390	72	2	1	2	2	5.194	14.3099
32	1	0	1	1	5.197	14.3145	73	2	2	0	0	5.229	14.3685
33	1	0	1	2	5.190	14.3028	74	2	2	0	1	5.238	14.3840
34	1	0	2	0	5.209	14.3349	75	2	2	0	2	5.219	14.3511
35	1	0	2	1	5.205	14.3279	76	2	2	1	0	5.244	14.3927
36	1	0	2	2	5.196	14.3130	77	2	2	1	1	5.224	14.3600
37	1	1	0	0	5.134	14.2083	78	2	2	1	2	5.212	14.3401
38	1	1	0	1	5.177	14.2775	79	2	2	2	0	5.219	14.3511
39	1	1	0	2	5.226	14.3632	80	2	2	2	1	5.239	14.3855
40	1	1	1	0	5.218	14.3491	81	2	2	2	2	5.191	14.3053
41	1	1	1	1	5.106	14.1487							

Table 9 - Three-way table for green density

	A0				A1				A2		
	C_0	C_1	C_2		C_0	C_1	C_2		C_0	C_1	C_2
B_0	14.2632	14.2058	14.2672		14.3115	14.3188	14.3253		14.3222	14.4089	14.2316
B_1	14.2547	14.2365	14.1415		14.283	14.266	14.2866		14.3384	14.3258	14.3437
B_2	14.1907	14.3379	14.4051		14.3486	14.4124	14.4706		14.3679	14.3642	14.3473

	A0				A1				A2		
	C_0	C_1	C_2		C_0	C_1	C_2		C_0	C_1	C_2
D_0	14.2453	14.1692	14.2838		14.2769	14.3774	14.3602		14.3252	14.3807	14.3084
D_1	14.2723	14.2774	14.2716		14.2988	14.2975	14.3492		14.3494	14.3687	14.3373
D2	14.191	14.3336	14.2585		14.3673	14.3223	14.3731		14.3538	14.3495	14.2769

Table 10 - ANOVA table for green density

Factor		Sum of Square	Degree of freedom	Variance	F	Significant	Contribution (%)
A		1.078	2	0.539	19.99	Strong	19.55
B		0.971	2	0.485	18.01	Strong	17.62
C	Polled	0.061	2				
D	Polled	0.019	2				
AB	Polled	0.255	4				
AC	Polled	0.222	4				
AD	Polled	0.140	4				
BC		0.507	4	0.127	4.71	Strong	9.21
BD	Polled	0.029	4				
CD	Polled	0.052	4				
ABC		0.769	8	0.096	3.56	Moderate	13.95
ABD	Polled	0.085	8				
BCD		0.309	8	0.039	1.43	Weak	5.60
ACD		0.559	8	0.070	2.59	Moderate	10.14
ABCD		0.456	16	0.029	1.06	Weak	8.28
(Error)		0.862	12	0.027			15.65

4. Conclusion

From Taguchi and analysis of variance results, the following can be concluded:

1. Taguchi method gives close results with analysis of variance. It is proven as an effective optimisation tool to optimise and analyse the process parameter of the moulding process.
2. The green defects and the green density have different significant factors and optimal level. Factor B, the mould temperature is the most significant factor for both quality characteristics. The optimal condition for the green defects is injection temperature: 150ºC, mould temperature: 70ºC, injection pressure: 550 are and flow rate: 15cm^3/s ($A_1B_2C_0D_1$) while green density is injection temperature: 160ºC, mould temperature: 70ºC, injection pressure: 650 bar and flow rate: 10cm^3/s ($A_2B_2C_1D_0$)
3. The interaction between injection temperature with mould temperature (AB), the interaction between mould temperature with flow rate (BD), the interaction between injection pressure with flow rate (CD) and interaction between injection temperature with mould temperature and injection pressure (ABC) give moderate effect to the green defects.
4. The interaction between injection temperature with mould temperature and injection pressure (ABC) and interaction between injection temperature with injection pressure and flow rate (ACD) give moderate effect to green density. The interaction between mould temperature with injection pressure (BC) is found to be a significant factor to green density.

5. Interactions between the parameter cannot be neglected in the optimisation of moulding parameter. Only interactions between four factors and above can be neglected.

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