Original Research Article

Optimization of Process Parameters Using Taguchi and ANOVA

Asnakew Sewale Belay[1,*], Fantahun Getie Tsegaw[2], Sisay Geremew Gebeyehu[2]

[1]University of Gondar, Gondar, Ethiopia
[2]Faculty of Mechanical and Industrial Engineering, Bahir-Dar Institute of Technology, Bahir-Dar University, Bahir-Dar, Ethiopia

Citation A.S. Belay, F.G. Tsegaw, S.G. Gebeyehu. Optimization of Process Parameters Using Taguchi and ANOVA. *J. Eng. Ind. Res.* **2024**, 5 (3):152-162.

https://doi.org/ 10.48309/jeires.2024.212593

Article info:
Submitted: 2024-11-17
Revised: 2024-11-26
Accepted: 2024-12-28
ID: JEIRES-2411-1135

Keywords:
Taguchi; Design of experiment; Shrinkage; Injection molding; ANOVA; S/N

ABSTRACT

The use of the best operating parameters is needed to produce better quality of plastic products. Since the quality of products is mostly influenced by process condition, determining the optimum process condition with a few experiments is a key task. Melting temperature, injection pressure and cooling time with three levels each were selected which directly affect the dimensional shrinkages in injection molding process of beverage crate product. Shrinkage is chosen as a response variable since it is cause of many defects. Taguchi method was selected for the optimization of these parameters. The objective of this research is to reduce the shrinkage of a crate. Nine types of crates were produced using Taguchi design of experiment (L^9) approach. Minitab statistical software package were used to analyze experimental results. The shrinkage defects are the “smaller the better S/N ratio” type of quality characteristics. Significant parameters were identified through ANOVA at 95% confidence level. Optimal values for melting temperature, injection pressure and cooling time were found 290 °C, 130 MPa, and 60 seconds, respectively. From analysis of variance, melting temperature was the most significant factor (14.7 %), cooling time was the second (11.5 %) and injection pressure was the least significant (9 %). The predicted optimum response variable (shrinkage) was found as 6.30 mm and the conformation experimental test gave 6.11mm. The margin error of 3% supported the acceptance of the confirmation test result of 6.11 mm. The shrinkage is reduced from 6.81 mm to 6.11 mm which is a 10.3% reduction. The identification of the influence of parameters is believed as a key factor in assisting injection molding process designers in determining optimum process conditions. Therefore, the implication of this research is that robust optimization approach withstands the injection molding process variations in a more realistic way.

Introduction

Plastic injection molding is one of the well-known manufacturing methods that able to produce intricate- shaped and large-sized products in short time at low cost. There are many process parameters that affect the plastic product defects. Shrinkage is one of the major defects in production of beverage crate product. The parameter optimization and Taguchi experimental design are needed to improve the product quality [1].

*Corresponding Author: Asnakew Sewale Belay (asnshsew@gmail.com)

Shrinkage cannot be eliminated completely in the injection molding process due to the fact that all polymer materials will undergo certain amount of contraction when it is cooled. However, shrinkage can be minimized by controlling and optimizing the injection molding process parameters [2]. The establishment of the experiment is the most significant step to improve the product or process quality. Therefore, quality could be designed into the product from the design stage of product or process. Therefore, the quality improvement can be continued through the production phase. According to this fact, experimental design based on Taguchi methodology is an influential and effective approach in producing good quality plastic products. Taguchi's approach provides engineers/designers with a systematic and proficient approach for conducting experiments with limited statistical skills to the study [3]. Finding the optimum factors using one factor-at-a-time experiments will not be very cheap and time consuming. Among various statistical experimental designs, Taguchi experimental design gives unique advantages by which many factors can be examined simultaneously and much quantitative information can be extracted with a few experiments [4]. The basic principle of this method enables to examine the effects of many process variables and identify those factors which have major effects on process [5]. The Taguchi method is to determine the optimum combination of process parameters, best value of response parameter, significance of process parameters and then percentage contribution of process parameters neglecting the variation caused by uncontrollable factors or noise factors [6]. The quality of an injection molding part can be divided in to three types: (a) dimensional characteristics like length, width and height; (b) surface properties, related to surface defects like sink mark, warpage, crack and voids. (c) Mechanical properties such as tensile and impact strength [7]. Based on the background, optimizing the process parameters for beverage crate may effectively contribute to minimize the shrinkage effect. Therefore, this research aims to optimize selected process parameters and minimize dimensional (length and width) shrinkage of beverage crate through the application of Taguchi's Design of Experiment in Plastic Injection Molding Manufacturing Company.

Literature review

The plastic product manufacturing company has different processes from the raw material reception to the final products. In plastic injection molding process, there are mainly three stages; injection phase filling phase, and cooling phase [8]. The main processes are described, as displayed in Figure 1.

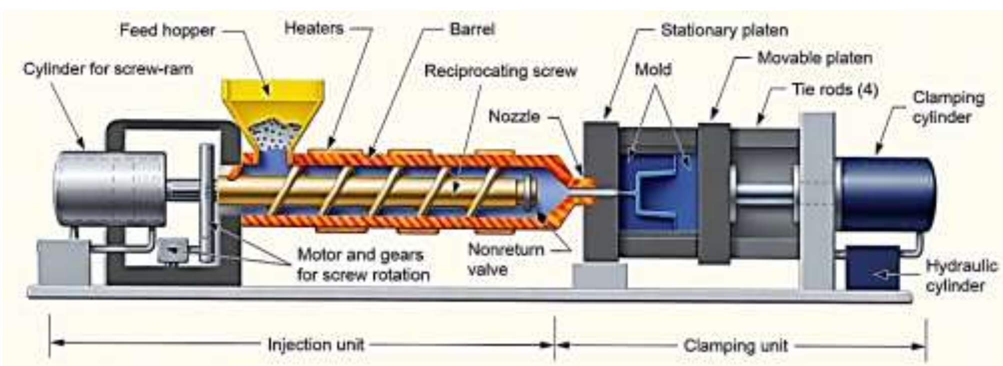

Figure 1: Injection molding machine functions

In optimization study, the steps consist of determining the design objectives, creating the DOE, simulation, and validation, creating a mathematical model, and finally optimization [9]. There are a number of studies that are relevant to the study of process parameter optimization in plastic injection molding using Taguchi methods; and few are discussed as follows. The following steps for the study are implemented in Taguchi's experimental design data analysis [10]. Selection of output or target parameters to be optimized; Identification of the input parameters affecting output variables and their levels; determining the suitable orthogonal array; Assign factors and interactions to the columns of the array; Conduct the experiments; Statistically analyze the result using analysis of variance and the S/N ratio; determining the optimum setting of the factor levels (process parameters) and Perform validation experiment. Final optimal process parameter setting is recognized as one of the most important steps in injection molding for improving the quality of molded products. Process conditions are the most influential for the quality of the injection molded plastic parts. hence, how to determine the optimum process factors becomes the crucial to improving the part quality [11]. Shrinkage is one of the most important reasons that cause dimensional changes in the part, and it can be minimized by setting optimal process parameters on injection molding machine [12]. Optimal setting up of injection molding process parameters plays a very significant role in controlling the quality of the injection molded products [13]. In the plastic injection molding various defects can't be completely removed by any other methods, but by using optimization techniques one can search for the optimal settings for injection molding process parameters, so that this defect (shrinkage) can be reduced up to desired level [14]. The study selected one of the part produced and applied on its process by selecting melting temperature, pressure and cooling time as a process parameters. Based on the result using ANOVA table, the melt temperature contributes the most percentage values of 96.1% and lastly cooling time which contributes the least to the shrinkage with 0.35% [15]. The influences of plastic injection molding machine process parameters on dimensional shrinkage were studied. Significant variables affecting the dimensional shrinkage were identified by ANOVA analysis. The result showed that most significant variable affecting dimensional shrinkage is melt temperature. The overall mean of dimensional shrinkage is 1.875 mm and optimum value of dimensional shrinkage of 1.275 mm [16].

It is studied to improve the quality characteristic (shrinkage) of an injection molding product (plastic tray), prepared from blends plastic (75% polypropylene (PP) and 25% low density polyethylene (LDPE) by optimizing the injection molding parameters uses the Taguchi approach. Melting temperature is the most significant parameter and the optimum total shrinkage is 0.1645 cm [17].

Materials and Methods

The present study followed a case study approach. The research methodology started with the identification of material used for beverage crate which is highly density polyethylene (HDPE). The high melt flow rate makes it ideal for molding of very thin, intricate and large items having adequate plasticity properties. This material is used for an ideal choice for making master batches with higher loading. The plastic beverage crate injection molding was produced on a DKM 780 injection molding machines.

Next, Selection of output (shrinkage) to be optimized was done. It proceeds with the collection of defects in case product from quality department's defect recording sheets at Tekrariwa Plastic Manufacturing Company (Case Company) and then the data was analyzed using cause and effect diagram. Cause and effect analysis was performed with the quality supervisor, production department and with shift operators. All the possible causes affecting plastic shrinkages are sorted out with the help of cause-and-effect diagrams. The shrinkage rejections were analyzed and plotted using histogram. Then, selection of parameters was performed using orthogonal arrays (L^9) with three factors and levels.

The three parameters were selected based on careful studying of literature and defect recording sheets. Assigning factors and interactions was then done. Next, shrinkage experimental tests were conducted to show the variation with standard dimension. In order to measure its shrinkage, after 24 h the crate produced, it was inserted on the plastic shrinkage oven test machines, which is shown at Figure 2: for 72 h (three days) at 60 °C. During the shrinkage dimensional measurement, a digital vernier caliper instrument was used. Thereafter, the results were analyzed using analysis of variance and Taguchi method of S/N ratio of "smaller the better" since the experiment was to minimize the shrinkage. Minitab18 software was used to analyze and interpret analysis of variance (ANOVA) and S/N ratio results. Based on the results, optimal settings were determined. Lastly, validation and checking the margin error were done to evaluate whether the optimum setting of parameters predicted were in the allowable range.

Figure 2: Shrinkage testing machine (oven)

The steps involved in the research starts with data collection from the case company and end with the validation test, as illustrated in Figure 3.

Data collection

There are various defects in plastic injection molding process which affects the quality of beverage crate. Common shrinkage defects which are observed in plastic injection molding that forced the product to rejection or to recycle process are Sink marks, Warpage, Crack, and Voids, as demosntrated in Figure 4. Table 1 and Figure 5 show the recorded defect products for each plastic injection mold parameter.

Data analysis

The number of defects per each parameter is illustrated Figure 5.

Cause and effect diagram

The main cause of shrinkage in plastic injection molding was, due to working process parameters, materials, operator, and machine. All the possible causes affecting plastic shrinkage are sorted out with the help of cause-and-effect diagram. The details are shown in Figure 6.

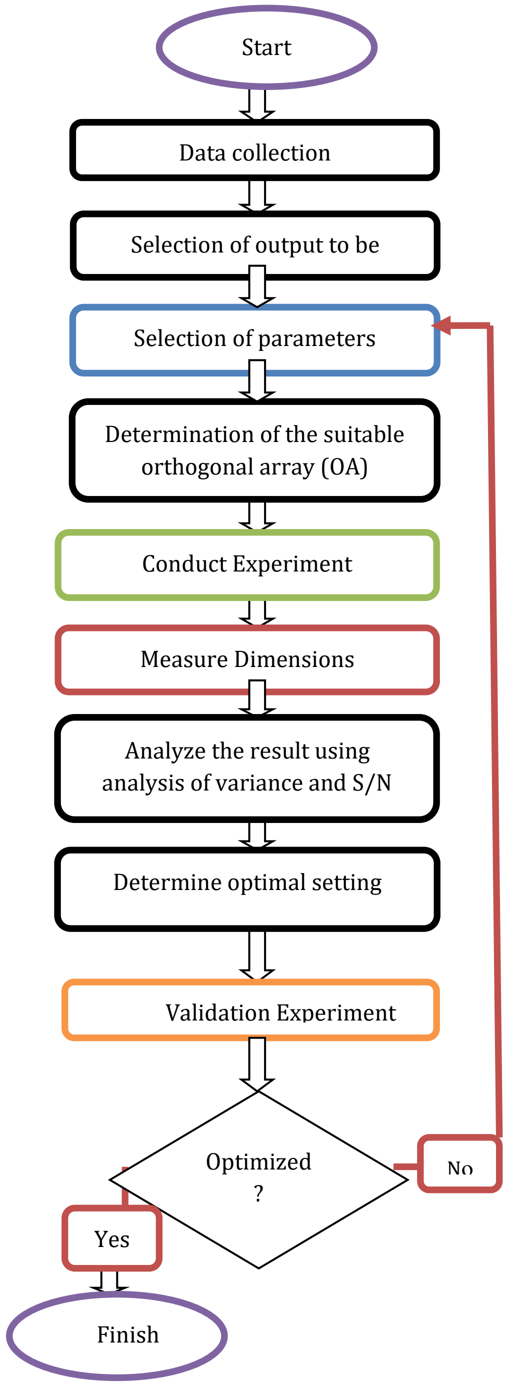

Figure 3: Steps involved in this study

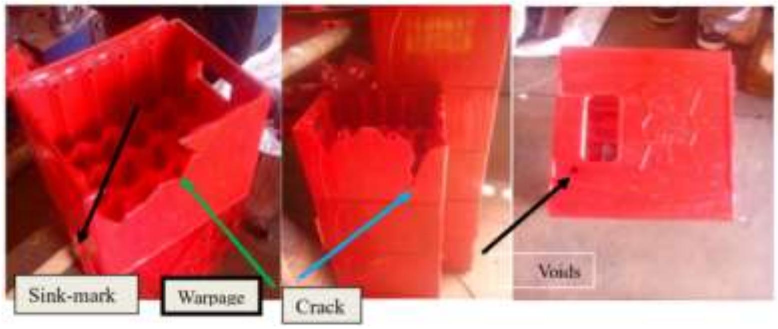

Figure 4: Different product defects due to parameters

Table 1: One month recorded defect products for each plastic injection mold parameters

Parameters	Week 1	Week 2	Week 3	Week 4	Total
Melting temperature	18	15	20	14	67
Injection pressure	11	20	16	17	64
Cooling time	8	13	10	13	44
Machine speed	3	-	1	-	4
Total defects	37	48	46	44	175

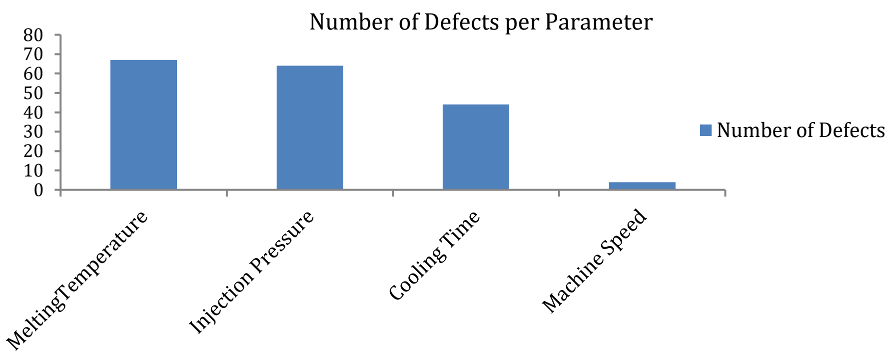

Figure 5: Number of defects per parameter

Selection of parameters and their levels

Based on careful studying of literature and defect recording sheets of the case company, the three parameters are selected as shown in Table 2 by removing those process parameters which has insignificant effect in the injection molding of plastic manufacturing process.

Determination of the suitable orthogonal array

For three process parameters and three levels L^9 orthogonal array was selected from the array selector as shown in Table 3.

Procedures for measuring shrinkage

The specimens were produced according to the trials of orthogonal array shown in Table 3 in DKM 780 injection molding machine.

Plastic beverage crate for 300ml bottles with holding capacity of 24 bottles was selected for experiment and produced from the plastic blend on the DKM 780T plastic injection molding machine. So, after 24 h the product (beverage crate) has been manufactured, it's original outside dimension (length, height & width), inside dimension (width and length), of the crate were measured with the help of digital vernier caliper measuring instrument. Subsequently, these dimensions are also measured after keeping the crate at oven shrinkage test machine under 60 °C for 72 h (3 days for each experiment run). Then after 72 h the beverage crate released from the oven machine and cooled for 3 h and then measuring all the dimensions in order to check the difference between original dimensions and the dimensions after 72 h, indicated the amount of shrinkage that took place in the inside and outside dimension of the crate in order to minimize shrinkage using ASTM D955 standard testing method for plastic products.

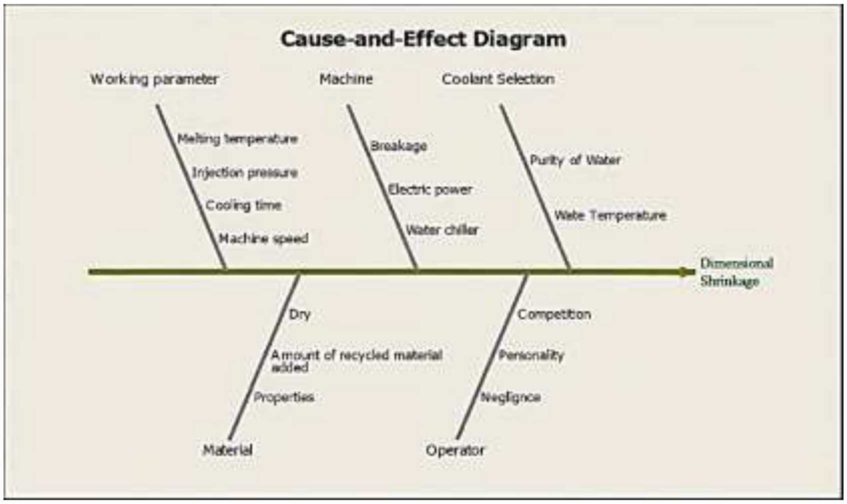

Figure 6: Fishbone diagrams for plastic shrinkage

Table 2: Injection molding parameters and their levels

Factor	Parameter	Unit	Level 1	Level 2	Level 3
A	Melting temperature	°C	280	285	290
B	Injection pressure	MPa	130	140	145
C	Cooling time	Sec	50	60	65

Table 3: Levels of process parameters used in Taguchi L^9 orthogonal array

Experiment No.	Column No. X	Y	Z
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

The experiment parameters have been carried out by considering confidence limit at 95%, statistically significant. The total shrinkage occurred in the dimension of the beverage crate for each experiment were calculated by adding the inside dimensions (length and width) and outside dimensions (length, height, and width) of the shrinkages [18].

2024, Volume 5, Issue 3

S/N ratio analysis

The amount of shrinkage obtained is used to calculate the signal to noise ratio(S/N) to get the optimal setting of the parameters. The objective is always to have higher value of S/N ratio which can be achieved by the peak point of the factors. Shrinkage is the objective function so that "the smaller the better" S/N ratio is chosen since the experiment is to minimize the shrinkage. The equation to obtain the values of S/N ratio is shown below. The S/N ratio for the smaller the better is:

$$\eta = -10log\frac{1}{r}\sum_{i=1}^{r} y_i^2$$

Where, η = S/N ratio, y_i = value of quality characteristics at i^{th} setting, r = total number of trial runs at i^{th} setting.

The amount of shrinkage for each specimen and the S/N ratio values is presented in Table 4.

The S/N ratio for each level of each factor can be calculated [19].

A sample of manual calculation of S/N ratio for melt temperature can be obtained as:

$$\text{Level 1} = \frac{1.40141+2.85335+3.88998}{3} = 2.715$$

$$\text{Level 2} = \frac{4.39365+1.14001+1.77685}{3} = 2.437$$

$$\text{Level 3} = \frac{3.78191+4.04081+2.10261}{3} = 3.308$$

Similarly, the results of S/N ratio for other parameters for each level are shown in Table 5.

Using minitab18 software the main effects plots for means and S/N ratios are obtained, as shown in Figure 7.

Analysis of variance (ANOVA)

ANOVA is performed to evaluate the significance of the injection molding process factor to the shrinkage. The significance is expressed in terms of relative contribution (in percentage) of each controlled parameter. The formula used in analysis of variance (ANOVA) table formation is as follows [20].

1. Total degree of freedom, f_T = N-1

9 – 1 = 8

Where N is the total number of results

Degree of freedom for each parameter

No. Levels – 1

For factor A, $f_A = k_A - 1$, 3 – 1 = 2, $f_B = 2$, $f_C = 2$

Where k_A is the number of levels for factor A

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

=8 – (2 +2 + 2) = 2

2. Total sum of squares

$$SS_T = \sum_{i=1}^{N} y_i^2 - \frac{(\sum T)^2}{N}$$

Where, T is the sum total of all Y (response) value and N is the total number of experiments

$$SS_T = 8.51^2 + 7.2^2 + 6.39^2 + 6.03^2 + 8.77^2 + 8.15^2 + 6.47^2 + 6.28^2 + 7.85^2 - \frac{(8.51 + 7.2 + 6.39 + 6.03 + 8.77 + 8.15 + 6.47 + 6.28 + 7.85)^2}{9}$$

SS_T = 487.7–478.88 = 8.82

Sum square of factor A

$$SS_A = \frac{(\sum A1)^2}{NA1} + \frac{(\sum A2)^2}{NA2} + \frac{(\sum A3)^2}{NA3} - \frac{(\sum T)^2}{N}$$

Where, N_{A1} is the number of values available at level 1 of parameter A

$$SS_A = \frac{(8.51 + 7.2 + 6.39)^2}{3} + \frac{(6.03 + 8.77 + 8.15)^2}{3} + \frac{(6.03 + 8.77 + 8.15)^2}{3} - 478.88$$

SS_A = 480.18– 478.88 = 1.3

Sum square of factor B:

$$SS_B = \frac{(\sum B1)^2}{NB1} + \frac{(\sum B2)^2}{NB2} + \frac{(\sum B3)^2}{NB3} - \frac{(\sum T)^2}{N}$$

Where, N_{B1} is the number of values available at level 1 of parameter B

$$SS_B = \frac{(8.51 + 6.03 + 6.47)^2}{3} + \frac{(7.2 + 8.77 + 6.28)^2}{3} + \frac{(6.39 + 8.15 + 7.85)^2}{3} - 478.88$$

SS_B = 479.68 – 478.88= 0.8

Sum square of factor C:

$$SS_C = \frac{(\sum C1)^2}{NC1} + \frac{(\sum C2)^2}{NC2} + \frac{(\sum C3)^2}{NC3} - \frac{(\sum T)^2}{N}$$

Where, N_{C1} is the number of values available at level 1 of parameter C

$$SS_C = \frac{(8.51 + 8.15 + 6.28)^2}{3} + \frac{(7.2 + 6.03 + 7.85)^2}{3} + \frac{(6.39 + 8.77 + 6.47)^2}{3} - 478.88$$

SS_C = 479.89 – 478.88 = 1.01

For error, SS_e

$SS_e = SS_T - (SS_A + SS_B + SS_C)$

= 8.82 – (1.3+0.8+1.01) = 5.71

3. For variance, V== $\frac{SS}{f}$

For factor A, $V_A = \frac{SSA}{fA} = \frac{1.3}{2} = 0.65$,

V_B = 0.40, V_C = 0.51

For error, $V_e = \frac{SSe}{fe} = \frac{5.71}{2} = 2.855$

4. F-ratio, $F = \frac{Veach}{Ve}$

For factor A, $F_A = \frac{VA}{Ve} = \frac{0.65}{2.855} = 0.23$,
$F_B = 0.14$, $F_C = 0.18$

5. Percentage contribution (P)

$p = \frac{SSeach*100}{SST}$

For factor A, $P_A = \frac{SSA*100}{SST} = \frac{1.3*100}{8.82} = 14.7$ %, PB = 9 %, PC = 11.5 %

The summary of analysis of variance (ANOVA) is shown in Table 6.

Table 4: Summary of results of shrinkage tests and S/N values

	Parameters			Response	S/N ratio
	A	B	C	Total shrinkage in (cm)	SNRA1
1	280	130	50	0.851	1.40141
2	280	140	60	0.720	2.85335
3	280	145	65	0.639	3.88998
4	285	130	60	0.603	4.39365
5	285	140	65	0.877	1.14001
6	285	145	50	0.815	1.77685
7	290	130	65	0.647	3.78191
8	290	140	50	0.628	4.04081
9	290	145	60	0.785	2.10261

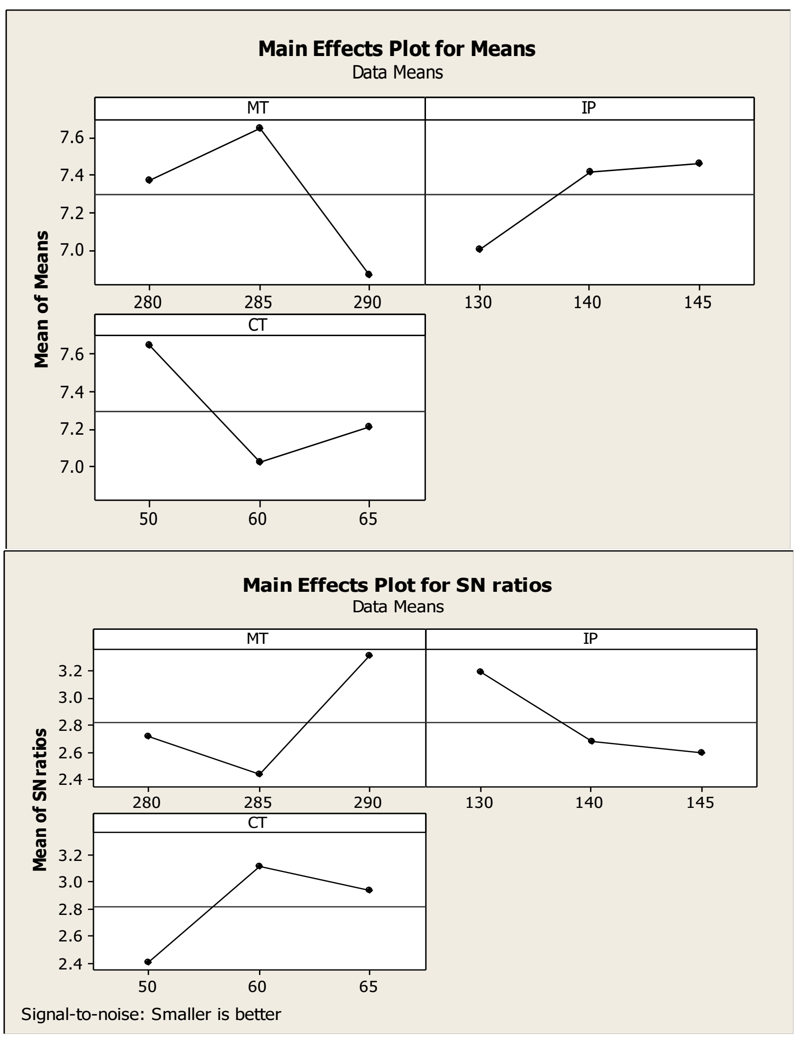

Figure 7: Main effect plots for mean response and S/N

Table 5: Response table of S/N ratio for each level of each factor

Level	Melting temperature(MT)	Injection pressure (IP)	Cooling time (CT)
1	2.715	3.192	2.406
2	2.437	2.678	3.117
3	3.308	2.590	2.937
Delta	0.872	0.603	0.710
Rank	1	3	2

Validation test

Validation test is required to assure the response values based on the optimum setting indeed better than the existing values. In this study, the validation test needs to be run to see whether the optimized settings can be used to reduce the existing mean shrinkage value (6.81 mm). Therefore, a validation experiment is conducted at the optimum setting of the process parameter, the melting temperature was set at 290 °C, injection pressure was set at 130 MPa and cooling time was set at 60 seconds and then the shrinkage test was performed. Therefore, the shrinkage validation test results for each dimension of the plastic crate are described on Table 7.

Table 6: Summary for ANOVA

Parameters	Degree of freedom (f)	Sum of square (SS)	Variance (V)	F	P (%)
Melting temperature	2	1.3	0.65	0.23	14.7
Injection pressure	2	0.8	0.40	0.14	9
Cooling time	2	1.01	0.51	0.18	11.5
Residual error	2	5.71	2.855		64.74
Total	8	8.82	1.56		100

Table 7: Shrinkage validation test result

Validation run	Shrinkage (mm)						Total shrinkage (mm)
	Outside dimensions (mm)			Inside dimensions (mm)			
	Width	Length	Height	Width	Length	Total	
1	1.18	1.28	1.34	1.23	1.08	6.11	6.11

After conducting the validation test, the result was again analyzed and compared with the Minitab values. This is used to evaluate whether the optimum setting of parameters predicted were in the allowable range. The predicted mean value using Minitab software is indicated in Table 7.

If the margin error from the prediction and the validation result was set below 10 %, then the validation test is acceptable [21-23]. The margin error was calculated by using the following formula:

$$\text{Margin error (\%)} = \left|\frac{(\text{validation test} - \text{predicted})}{\text{Predicted}}\right| * 100 \quad (12) = \left|\frac{(6.11 - 6.30)}{6.30}\right| * 100 = 3\%$$

Results and Discussion

To know the significance of process parameters on dimensional shrinkage on the crate product, S/N analysis can be performed and the rank of each parameter can be assigned based on delta statistics (maximum difference). The value with the highest delta is ranked highest and lowest delta ranked least. Hence, from the response table of S/N ratio for each level of each factor, as shown in Table 5, melting temperature ranked first which is the most significant factor followed by cooling time and injection pressure is ranked third which is the least significant factor.

Main effect plots for mean response and S/N, as shown in Figure 7, indicated that the recommended setting of parameters for shrinkage was produced by the combination of A3, B1, and C2.That was the setting of melt temperature with 290°C, injection pressure of 130 MPa and cooling time of 60 seconds.

From the ANOVA table, it was shown that the melt temperature (A) contributes the most percentage values which is 14.7% followed by cooling time which contributed 11.5 % and lastly the injection pressure which contributes the least with 9%.

Shrinkage validation test result from in Table 7 is 6.11 mm and the predicted mean value using Minitab software from Table 7 is 6.30 mm. Therefore, the margin error based on validation test result and predicted mean value is 3% which is below 10 %. So, it indicated that the validation test is accepted as it confirmed that the recommended parameter setting reduced the shrinkage defects according to this research.

The percentage contribution of residual error was more than expected. This might be due to the Interaction effects. Therefore, interaction effects will be taken into account in the future work.

Conclusion

In injection molding process of beverage plastic crate, for shrinkage melting temperature is found to be the most significant parameter which contributes 14.7% followed by cooling time with 11.5% and lastly injection pressure by 9%. To achieve the minimum shrinkage, it is recommended to operate with the best settings of process parameters in terms of shrinkage at 290 °C, 130 MPa, and 60 seconds for melting temperature, injection pressure and cooling time respectively. The margin error of 3% supported the acceptance of the confirmation test result of 6.11 mm. In the case product the shrinkage is reduced from 6.81 mm to 6.11 mm which is a 10.3% reduction. This is a significant improvement that greatly affects the insertion of the bottles. Since most defects such as Sink marks, Warpage, Crack, and Voids come from the shrinkage defect directly or indirectly, a small improvement in shrinkage has a vital effect on overall quality of the product. From this research, it can be inferred that Taguchi methodology can be used to reduce the shrinkage defects. It is a very valuable method that can be used to provide efficient method instead of trial and error methods which is uneconomical. The identification of the influence of parameters is believed as a key factor in assisting injection molding process designers in determining optimum process conditions. Hence, the implication of this research is that robust optimization approach withstands the injection molding process variations in a more realistic way. No interactions between the input parameters are taken in to account which might have affected the result. In addition, much of this research is focused to improve the quality of product through the process optimization. But the costs associated with this improvement drive are not accounted anywhere in this study. Therefore, future research should incorporate cost.

ORCID

Asnakew Sewale Belay
https://orcid.org/0009-0008-4808-8159
Fantahun Getie Tsegaw
https://orcid.org/0009-0000-4656-4547
Sisay Geremew Gebeyehu
https://orcid.org/0000-0002-2901-7995

Reference

[1]. P. Benardos, G.C. Vosniakos, Predicting surface roughness in machining: a review, *International Journal of Machine Tools and Manufacture*, **2003**, *43*, 833-844. [Crossref], [Google Scholar], [Publisher]

[2]. T. Bhirud, R. Metkar, Experimentation and optimization of shrinkage in plastic injection molded GPPS part, *International Conference on Communication and Signal Processing 2016 (ICCASP 2016)*, *Atlantis Press*, **2016**, 107-112. [Crossref], [Google Scholar], [Publisher]

[3]. D. Mathivanan, M. Nouby, R. Vidhya, Minimization of sink mark defects in injection molding process–Taguchi approach, *International Journal of Engineering, Science and Technology*, **2010**, *2*, 13-22. [Crossref], [Google Scholar], [Publisher]

[4]. V.V. Dasu, T. Panda, M. Chidambaram, Determination of significant parameters for improved griseofulvin production in a batch bioreactor by Taguchi's method, *Process Biochemistry*, **2003**, *38*, 877-880. [Crossref], [Google Scholar], [Publisher]
[5]. R. Fletcher, Practical methods of optimization, *John Wiley & Sons*, **2000**. [Google Scholar], [Publisher]
[6]. M. Mustaffa, H. Radhwan, A. Annuar, H. Azmi, M. Zakaria, A. Khalil, An optimization of shrinkage in injection molding parts by using Taguchi method, *Journal of Advanced Research in Applied Mechanics*, **2015**, *10*, 1-8. [Google Scholar], [Publisher]
[7]. S. Kamaruddin, Z.A. Khan, S. Foong, Application of Taguchi method in the optimization of injection moulding parameters for manufacturing products from plastic blend, *International Journal of Engineering and Technology*, **2010**, *2*, 574. [Google Scholar]
[8]. D. Kumar, A. Kapoor, Optimization of process parameters in injection-molding by recent methods for optimization—literature review, National conference on sustainable and emerging trends in mechanical engineering "NCSETME, **2018**. [Google Scholar]
[9]. M.S. Meiabadi, A. Vafaei, F. Sharifi, Optimization of plastic injection molding process by combination of artificial neural network and genetic algorithm, *Journal of Optimization in Industrial Engineering*, **2013**, *6*, 49-54. [Google Scholar], [Publisher]
[10]. V.K. Modi, D.A. Desai, Status of six sigma and other quality initiatives in foundries across the globe: a critical examination, *International Journal of Applied Industrial Engineering (IJAIE)*, **2017**, *4*, 65-84. [Google Scholar], [Publisher]
[11]. J. Osarenmwinda, D. Olodu, Optimization of injection moulding process parameters in the moulding of high-density polyethylene (HDPE), *Journal of Applied Sciences and Environmental Management*, **2018**, *22*, 203–206. [Crossref], [Google Scholar], [Publisher]
[12]. R. Pareek, J. Bhamniya, Optimization of injection moulding process using Taguchi and ANOVA, *International Journal of Scientific & Engineering Research*, **2013**, *4*, 1-6. [Google Scholar], [Publisher]
[13]. M.S. Phadke, Quality engineering using robust design, Prentice Hall PTR1995. [Google Scholar], [Publisher]
[14]. R. Ramakrishnan, K. Mao, Minimization of shrinkage in injection molding process of acetal polymer gear using Taguchi DOE optimization and ANOVA method, *International Journal of Mechanical and Industrial Technology*, **2017**, *4*, 72-79. [Google Scholar], [Publisher]
[15]. S. Shahravi, M.J. Rezvani, A. Jahan, Multi-response optimization of grooved circular tubes filled with polyurethane foam as energy absorber, *Journal of Optimization in Industrial Engineering*, **2019**, *12*, 133-149. [Google Scholar], [Publisher]
[16]. N. Shuaib, M. Ghazali, Z. Shayfull, M. Zain, S. Nasir, Warpage factors effectiveness of a thin shallow injection-molded part using Taguchi method, *International Journals of Engineering & Technology*, **2011**, *11*, 2077-1185. [Google Scholar], [Publisher]
[17]. G. Singh, M. Sayad, Effect of injection moulding process parameter on warpage of using Taguchi method, *International Research Journal of Engineering and Technology (IRJET)*, **2019**, *6*, 2395-0056. [Google Scholar], [Publisher]
[18]. R. Stone, A. Veevers, The Taguchi influence on designed experiments, *Journal of Chemometrics*, **1994**, *8*, 103-110. [Crossref], [Google Scholar], [Publisher]
[19]. T. Sivarao, S. Ammar, RSM based modeling for surface roughness prediction in laser machining, *International Journal of Engineering & Technology IJETIJENS*, **2010**, *10*. [Google Scholar], [Publisher]
[20]. B. Young, H. Yarranton, C. Bellehumeur, W. Svrcek, An experimental design approach to chemical engineering unit operations laboratories, *Education for Chemical Engineers*, **2006**, *1*, 16-22. [Crossref], [Google Scholar], [Publisher]
[21]. A. Johnson, Investigating the effects of environmental applications on decomposition of zein nanoparticles in adsorbents in industry, *Journal of Engineering in Industrial Resaerch*, **2023**, 4, 92-108. [Crossref], [Google Scholar], [Publisher]
[22]. K.M. Elsherif, H. Aberrwaila, A.S. Aburowais, A.M. Etwaish, A.M. Elassawi, complexation of Ag (I) with 8-hydroxyquinoline: Synthesis, spectral studies and antibacterial activities, *Advanced Journal of Chemistry-Section A*, **2022**, *5*, 138. [Crossref], [Google Scholar], [Publisher]
[23]. R. Tyagi, A. Chaudhary, D. Dangi, A. Singh, M. Yusuf, Application of Design of Experiment (DoE) for Optimization of Multiple Parameter Resource Constrain Process: Taguchi-Based Fractional Factorial Approach, *Advanced Journal of Chemistry, Section A*, **2023**, *6*, 391-400. [Crossref], [Google Scholar], [Publisher]