Parametric Investigation for PP Homopolymer (1110MAS) in Plastic Injection Molding Process using Taguchi Method

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ABSTRACT

This paper deals on an optimization of plastic injection molding process by the effects of processing parameters applying Taguchi methods to improve the quality of manufactured specimen. PP homopolymer 1110MAS is used as the work piece material for carrying out the experimentation to optimize the shrinkage and warpage. The specimen used were of 169*16*3.2 mm dimensions modeled in PRO/Engineer. There are five processing parameters i.e. injection pressure, melt temperature, holding pressure, injection time & cooling time. Taguchi L_{18} orthogonal array is used to design experimentation withmixed levels of input parameters. The shrinkage and warpage was considered as the quality characteristic with the concept of "the smaller-the-better". The result of minimum shrinkage using the parameter combination of injection pressure 45 bar, Melt Temperature 175 ^{0}C, Holding pressure 30 bar, Injection time 4.2 s and cooling time 15 s is 4.133%. Whereas the result of minimum warpage using the parameter combination of injection pressure 45 bar, melt temperature 175 ^{0}C, holding pressure 30 bar, injection time 4.5 s and cooling time 20 s is 0.667 mm. It is also predicted that Taguchi method is a good method for optimization of various machining parameters as it reduces the number of experiments.

Keywords: Injection Molding, Taguchi Method, S/N Ratio, Shrinkage and Warpage.

1. INTRODUCTION

Injection molding is the most important process for manufacturing plastic parts. It is suitable for mass producing articles, since raw material can be converted into a molding by a single procedure. In most cases finishing operations are not necessary. An important advantage of injection molding is that with it we can make complex geometries in one production step in an automated process. The injection molding technique has to meet the ever increasing demand for a high quality product (in terms of both consumption properties and geometry) that is still economically priced. Injection Molding is a cyclic process for producing identical articles from a mold, and is the most widely used for polymer processing. The main advantage of this process is the capacity of repetitively fabricating parts having complex geometries at high production rates. Complexity is virtually unlimited and sizes may range from very small to very large. Most polymers may be injection molded, including thermoplastics, fiber reinforced thermo plastics, thermosetting plastics, and elastomers. Critical to the adoption of this high volume, low cost process technology is the ability to consistently produce quality parts.[1]

Taguchi method approach provides a new experimental strategy in which a modified and standardized form of design of experiment (DOE) is used. This technique helps to study effect of many factors (variables) on the desired quality characteristic most economically. By studying the effect of individual factors on the results, the best factor combination can be determined. Taguchi designs experiments using specially constructed tables known as "orthogonal array" (OA). The use of these tables makes the design of experiments very easy and consistent and it requires relatively lesser number of experimental trials to study the entire parameter space. The experimental results are then transformed into a signal-to-noise (S/N) ratio. Usually, there are three categories of quality characteristic in the analysis of the S/N ratio, i.e. the-lower-the-better, the-higher-the-better, and the nominal-the-better. The S/N ratio for each level of process parameters is computed based on the S/N analysis. Furthermore, a statistical analysis of variance (ANOVA) is performed to see which process parameters are statistically significant. With the S/N and ANOVA analyses, the optimal combination of the process parameters can be predicted. Finally, a confirmation experiment is conducted to verify the optimal process parameters obtained from the parameter design.Taguchi method stresses the importance of studying the response variation using the signal–to–noise (S/N) ratio, resulting in minimization of quality characteristic variation due to uncontrollable parameter.

Ozcelik et al. [2] has performed research to determine the factors i.e. melt temperature, packing pressure, cooling time and injection pressure that contribute to the mechanical properties such as elasticity module, tensile strength and tensile strain at yield, tensile strain at break, flexural modules and izod impact strength (notched) of Acrylonitrile–Butadiene–Styrene (ABS) moldings was considered. The process is performed by Taguchi's L_9orthogonal array design was employed for the experimental plan. Signal to noise ratio for mechanical properties of ABS using the Taguchi method was calculated and effect of the parameters on mechanical properties was determined using the analysis of variance.

Ozcelik, et al. [3] has optimized the injection molding process parameters such as melt temperature and packing pressure on the mechanical strength were investigated. Mechanical properties such as tensile strength and izod impact strength (notched) of the specimens were measured by test methods. The effect of molecular orientation on the mechanical properties of the specimens was discussed by Finite Element Analysis.

Mehatand Kamaruddin [4] has optimized the injection molding process parameters such as melt temperature, packing pressure, injection time, and packing time, each at three levels, are tested to determine the optimal combination of factors and levels in the manufacturing process. This study aims to improve the mechanical properties of products made from recycled plastic by utilizing the Taguchi optimization method, instead of coupling the products with additives.

Tsai et al. [5] has performed research to determine the factors that contribute to quality characteristics chosen such as light transmission, surface waviness and surface finish. The factors that been taking into considerations includes Melt temperature, Screw speed, Injection speed, Injection pressure, packingpressure, packing time, mold temperature, cooling rate. Three different regression methods are used, namely, linear, exponential and nonlinear regression. Verification experiments are executed to examine the accuracy of the regression model for predicting quality characteristics of lenses.

Chen, et al. [6] has optimized the injection molding process parameters such as Melt temperature, Mold temperature, Inject speed, Packing pressure with the application computer-aided engineering integrating with statistical technique to reduce warpage variation depended on injection molding process parameters during production of thin-shell plastic components. For this purpose, a number of Mold-Flow analyses are carried out by utilizing the combination of process parameters based on three level of L_{18} orthogonal array table. In this study, regression models that link the controlled parameters and the targeted outputs are developed, and the identified models can be utilized to predict the warpage at various injection molding conditions.

B. Ozcelik and T. Erzurumlu [7] has performed research to determine the factors that contribute to investigate the effects of process parameters for thin shell plastic part were exploited using both design of experiment (DOE), Taguchi orthogonal array and finite element software Mold-flow (FE). The most important process parameters influencing warpage are determined using finite element analysis results based on analysis of variance (ANOVA) method. Artificial neural network (ANN) is interfaced with an effective GA to find the minimum warpage value. Process parameters such as mold temperature, melt temperature, packing pressure, packing time, cooling time, runner type and gate location are considered as model variables.

Aashiq et al. [8] The purpose of the research is to explore the influence of different mold temperatures on the warpage & shrinkage of the injection molded component's. The simulation software MOLDEX 3D was used for this study, the simulations were done by varying different mold temperatures and their corresponding warpage & shrinkage were collected. So it is required to assure homogeneous mold wall temperature across the entire cavity during the production of injection molded parts.

Babur Ozcelik [9] optimized effect of injection parameters and weld line on the mechanical properties of polypropylene (PP) moldings. Melt temperature, packing pressure and injection pressure were investigated to study their effects on the mechanical strength of specimens with/without weld lines. Taguchi's L_9 orthogonal array design was employed for the experimental plan. Signal to noise ratio for mechanical properties of PP using Taguchi method was calculated and effect of the injection parameters and weld line on mechanical properties was determined using the analysis of variance (ANOVA). Linear models were also created by using regression analysis.

Chang,et al. [10] presents a fast and effective methodology for the optimization of the injection molding process parameters of short glass fiber reinforced polycarbonate composites. Various injection molding parameters, such as filling time, melt temperature, mold temperature and ram speed were considered. The methodology combines the use of the GRA (grey relational analysis) method and a CAE Mold-flow simulation software, to simulate the injection molding process and to predict the fiber orientation. At the same time, the fiber orientation was examined by CAE simulation to forecast the shear layer thickness, and simultaneously to check the accuracy of the GRA.

M.-S. Huang and T.-Y. Lin [11] proposes an advanced searching method for setting the robust process parameters for injection molding based on the principal component analysis (PCA) and a regression model-based searching method. This method could effectively reduce the influence of environmental noise on molded parts' multi-quality characteristics in the injection molding process. The design of experiment and ANOVA methods are then used to choose the major parameters, which affect parts quality and are called as adjustment factors. Based on this mathematical model, the steepest decent method is used to search for the optimal process parameters. To verify the performance, computer simulations and experiment of the light-guided plate molding were investigated in this work.

This paper discusses the use of Taguchi method for the injection molding process of PP Homopolymer MAS1110. In this study Taguchi's L18 orthogonal table was applied to perform the experimentation. Five controlling factors of injection pressure, melt temperature, holding pressure, injection time & cooling time with three levels for each factor were selected. The volumetric shrinkage and warpage are selected quality objectives as response parameters. By implementing DOE method is utilized to obtain S/N ratio 'smaller is better' approach. The result of minimum shrinkage using the parameter combination of injection pressure 45 bar, melt temperature 175 C, holding pressure 30 bar, injection time 4.2 sec and cooling time 15 sec is 4.133%. Whereas the result of minimum shrinkage using the parameter combination of injection pressure 45 bar, melt temperature 175 C, holding pressure 30 bar, injection time 4.5 sec and cooling time 20 sec is 0.667 mm.

2. METHODOLOGY

The general dimensions of the specimen were 169*16*3.2 mm. The injection molding machine and material used in the experimentation adhered to the following specifications: JIT 80 T(Microprocessor Controlled Injection molding machine) at CIPET, Aurangabad and PP Homopolymer 1110MAS . The process parameters injection pressure, melt temperature, holding pressure, injection time & cooling time, are some of the most significant parameters that affect volumetric shrinkage and warpage, as shown in previous research findings.

Table 1.Physical and mechanical properties of material [CIPET, Aurangabad]

Properties	Test method	Values
Physical properties		
Melt flow index g/10 min	ASTM D 1238	11.0
Density, g/cm^3	ASTM D 1505	0.9
Mechanical Properties		
Tensile strength at yield, MPa	ASTM D 638	42
Elongation at yield, %	ASTM D 638	8
Flexural modulus, MPa	ASTM D 790	1800
Thermal properties		
Heat deflection temperature, ^{0}C	ASTM D 648	115
Vicat Softening Point, ^{0}C	ASTM D 1525	154

2.1 Range and Levels of Process Parameters

The range of processing parameters is decided by taking number of trial using same material and machine also.

Table 1: Range and levels of process parameters

Name of parameter	Notations used	Unit of parameter	Range of parameter	Levels		
				1	2	3
InjectionPressure	A	bar	45-55	45	50	-
Melt Temperature	B	^{0}C	175-195	175	185	195
Holding pressure	C	bar	30-50	30	40	50
Injection time	D	s	40-45	4	4.2	4.5
Cooling time	E	s	15-25	15	20	25

The selection of an appropriate orthogonal array (OA)depends on the total degrees of freedom of the parameters. Degrees of freedom are defined as the number of comparisons between process parameters that need to be made to determine which level is better and specifically how much better it is. In this study, since each parameter has three levels. Basically, the degrees of freedom for the OA should be greater than or at least equal to those for the process parameters. Therefore, an L_{18} orthogonal array with five columns and eighteen rows was appropriate and used in this study. The experimental layout for the injection molding parameters using the L_{18} OA is shown in Table 2. Each row of this table represents an experiment with different combination of parameters and their levels. However, the sequence in which these experiments are carried is randomized.

Table 2: Taguchi L18 orthogonal array

	Input parameters				
Iteration No.	Injection Pressure (bar)	Melt Temperature (^{0}C)	Holding pressure (bar)	Injection time (s)	Cooling time (s)
1	45	175	30	40	15
2	45	175	40	42	20
3	45	175	50	45	25
4	45	185	30	40	20
5	45	185	40	42	25
6	45	185	50	45	15
7	45	195	30	42	15
8	45	195	40	45	20
9	45	195	50	40	25
10	50	175	30	45	25
11	50	175	40	40	15
12	50	175	50	42	20
13	50	185	30	42	25
14	50	185	40	45	15
15	50	185	50	40	25
16	50	195	30	45	20
17	50	195	40	40	25
18	50	195	50	42	15

The test results were evaluated in terms of signal/noise (S/N)ratio. The S/N was calculated by smaller is better for determining effect of injection process parameters on shrinkage and warpage of the specimen. The formula for S/N ratio is as follows

Smaller- the- better -It is used where minimization of the characteristics is intended.

$$S/N = -10\log_{10}\left[\frac{1}{n}\sum_{r=3}^{n}\frac{1}{{y_i}^2}\right] \quad (1)$$

2.3 Response Measurement

A) Shrinkage Measurement

It is the difference between the volume of mould cavity and volume of finished part divided by volume of the mould.

S = (Vm-Vp) / Vm X 100

where, Vm is Volume of mould, Vp is Volume of specimen and S is the shrinkage.

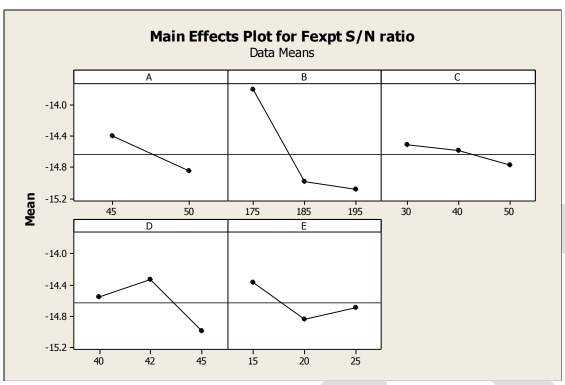
Vm is calculated using CAD 2014 &Vp is calculated by Weight/density as density is constant (0.9g/cm^3) and weight of each specimen was taken by using Precision weighing balance AB-204-S FACT after experimentation.

B) Warpage Measurement

Warpage is a distortion where the surfaces of the molded part do not follow the intended shape of the design. The feeler gauge is used to measure the warpage.Feeler gauges usually come with many different metal blades attached. These blades are not sharp and are used to measure gap distance. As such, a feeler gauge is useful when the gap between two surfaces needs to be exact, such as when setting the gap.

3. RESULTS AND DISCUSSION

3.1 Experimental result



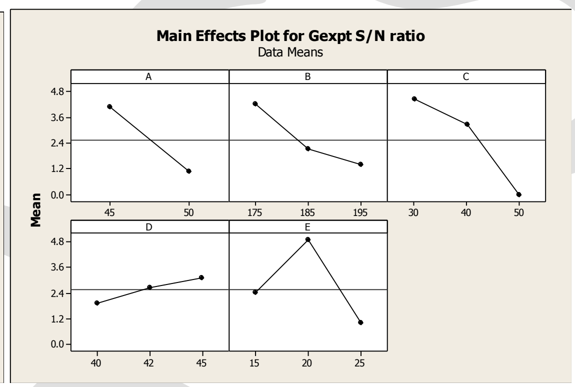
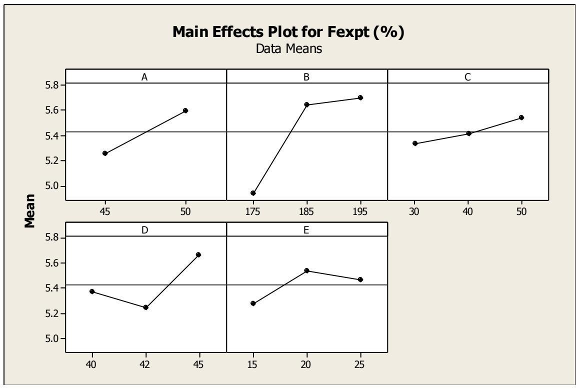


Fig. 3.1 Main Effect plot for volumetric shrinkage S/N ratio   Fig. 3.2 Main Effect plot for warpage S/N ratio

The main effect plots for S/N ratio for shrinkage (experimental) Vs each input parameter are shown in figure3.1.In the experimental analysis of S/N ratio, factor level will be selected to give maximum S/N ratio as the most suitable factor level. The selection of the most suitable factor level from the graph found that level of factorIt shows that the appropriate set of input parameters is A1 B1 C1 D2 E1 to minimize the volumetric shrinkage from conducting 18 number of experiments parameters namely Injection pressure (A), melt temperature (B), Holding pressure (C), Injection time (D) and cooling time(E). The effect of input parameters on the warpage shown above figure 3.2 for S/N ratio.The main effect plots for S/N ratio for warpage (experimental) Vs each input parameter are shown in figure. It shows that the appropriate set of input parameters is A1 B1 C1 D3 E2 to minimize the volumetric shrinkage from conducting 18 number of experiments parameters namely Injection pressure (A), melt temperature (B), Holding pressure (C), Injection time (D) and cooling time(E).



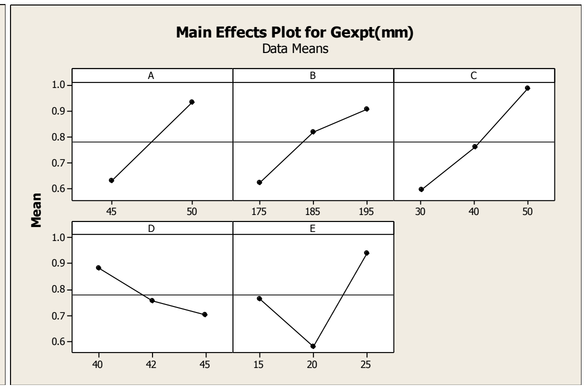


Fig. 3.3 Main Effect plot for Volumetric shrinkage

Fig. 3.4 Main effect plot for warpage

The main effect plots for shrinkage (experimental) Vs each input parameter are shown in figure 3.3.In the experimental analysis of main effect plot, factor level will be selected to give minimum main effect as the most suitable factor level. The selection of the most suitable factor level from the graph found that level of factor whichshows that the appropriate set of input parameters is A_1 B_1 C_1 D_2 E_1 to minimize the volumetric shrinkage from conducting 18 number of experiments parameters namely Injection pressure (A), melt temperature (B), Holding pressure (C), Injection time (D) and cooling time(E).

The main effect plots for warpage (experimental) Vs each input parameter are shown in figure3.4. It shows that the appropriate set of input parameters is A_1 B_1 C_1 D_3 E_2 to minimize the warpage from conducting 18 number experimentsparameters namely Injection pressure (A), melt temperature (B), Holding pressure (C), Injection time (D) and cooling time(E).

4. CONFIRMATION TEST

The purpose of confirmation experiment is to validate the conclusions drawn during the analysis phase. After determining the optimal level of process parameters, a new experiment is designed and conducted with optimum levels of plastic injection molding process parameters.

At the end we get the appropriate set of input parameters form experimentation result was A_1 B_1 $C_1D_2E_1$ to minimize the shrinkage. Whereas we get the appropriate set of input parameters form experimentation result is A_1 B_1 $C_1D_3E_2$ to minimize the warpage.

The confirmation test was conducted for the appropriate set of input parameters i.e for shrinkage it is A_1 B_1 C_1 D_2 E_1 and for warpage it is A_1 B_1 C_1 D_3 E_2.

Table 4.1 Confirmation test for volumetric shrinkage

Iteration No.	A	B	C	D	E	Fexpt
1	45	175	30	4.2	15	4.133

Table 4.2 Confirmation test for warpage

Iteration No.	A	B	C	D	E	Gexpt
1	45	175	30	4.5	20	0.667

The confirmatory experiments were performed using the optimal values and it was found that the experimental values were close enough to the required values. These values gives the reduction in volumetric shrinkage of 3.75 % and for warpage is of 2.54 %. The percentage reduction of response parameters shows that the optimized set of input parameters for plastic injection molding is good enough for minimizing the volumetric shrinkage and warpage also.

5. CONCLUSION

In this work, the experimental investigations has been reported for optimization of parameters influencing the volumetric shrinkage and warpage in plastic injection molding process. The report focuses on the optimization related to parameters of plastic injection molding process using experimentation analysis tool. Taguchi orthogonal array, S/N ratio and ANOVA method are very powerful tools to minimize volumetric shrinkage and warpage and can be successfully employed to improve injection molding of other plastic parts with complex geometry. Based on the results of the experimental analysis carried out, the following general conclusions were drawn

1. The melt temperature was the most influencing parameter followed by injection time, injection pressure, cooling time and holding pressure in sequence for controlling the volumetric shrinkage.
2. The cooling time was the most influencing parameter followed by holding pressure, injection pressure, melt temperature and injection time in sequence for controlling thewarpage.
3. The optimal set for minimizing the volumetric shrinkage was of injection pressure 45 bar, Melt Temperature 175 ^{0}C, Holding pressure 30 bar, Injection time 4.2 s and cooling time 15 s.
4. The optimal set for minimizing the warapge was injection pressure 45 bar, melt temperature 175 ^{0}C, holding pressure 30 bar, injection time 4.5 s and cooling time 20 s.
5. Using the optimal set the volumetric shrinkage reduces to 3.75 % which the least than experimental values.
6. Using the optimal set the warapge reduces to 2.54 %.which the least than experimental values..

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