Optimization of Injection Moulding Process Parameters Study in Plastic Injection Moulding Process using Statistical Methods

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***Abstract*— Dimensional changes because of shrinkage is one of the most important problems in production of plastic parts using injection molding. In this study, effect of injection molding parameters on the shrinkage in polypropylene (PP) and polystyrene (PS) is investigated. The relationship between input and output of the process is studied using regression method and Analysis of Variance (ANOVA) technique. To do this, existing data is used. 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 modeling. For modeling the process, different types of regression equations including linear polynomial, Quadratic polynomial and logarithmic function, are used to interpolate experiment data. Next, using step backward elimination and 95% confidence level (CL), insignificant parameters are eliminated from model. To check validity of the PP model, correlation coefficient of each model is calculated and the best model is selected. The same procedure is repeated for the PS model. Finally, optimum levels of the input parameters that minimize shrinkage, for both materials are determined. Invasive Weed Optimization (IWO) algorithm is applied on the developed mathematical models. The optimization results show that the proposed models and algorithm are effective in solving the mentioned problems.**

***Index Terms*- Injection pressure, melting temperature, refilling pressure, cooling time, shrinkage, S/N ratio, Taguchi method.**

I. INTRODUCTION

Injection moulding is a manufacturing process for producing parts by injecting material into a mould. Injection moulding can be performed with a host of materials, including metals, glasses, elastomers, confections, and most commonly thermoplastic and thermosetting polymers. Material for the part is fed into a heated barrel, mixed, and forced into a mould cavity where it cools and hardens to the configuration of the cavity. After a product is designed, usually by an industrial designer or an engineer, moulds are made by a mouldmaker (or toolmaker) from metal, usually either steel or aluminum, and precision-machined to form the features of the desired part. Injection moulding is widely used for manufacturing a variety of parts, from the smallest components to entire body panels of cars.

Parts to be injection moulded must be very carefully designed to facilitate the moulding process.The material used for the part, the desired shape & features of the part, the material of the mould and the properties of the moulding machine must all be taken into account. The versatility of injection moulding is facilitated by the breadth of design considerations and possibilities. Shrinkage is one of the most important reasons that causes dimensional changes in the part and it can be minimized by setting optimal process parameters on injection moulding machine. M.C. Huang and C.C. Tai [4] studied the effect of five input parameters on surface quality of thin moulded parts. The input parameters were mould temperature, melting temperature, packing pressure, packing time and injection time. Altan [5] utilized Taguchi method to optimize shrinkage of plastic, PP and PS, injection moulding parts. He also applied neural network to model the process and was able to achieve 0.937% and 1.224% shrinkage in PP and PS, respectively. Neeraj Singh C [6] showed how cycle time reduction can be done on injection moulding machine for DVD manufacturing by optimizing the parameter of injection moulding machine. He showed that by

optimizing the effective distance travel & speed of mould the DVD moulding cycle time can be reduced. Similarly, the cooling time and hold time are also effective parameters to reduce cycle time. Alireza Akbarzadeh and Mohammad Sadeghi [8] studied the relationship between input and output of the process using ANOVA. He considered four input parameters such as melting temperature, packing pressure, packing time & injection time and found that the packing pressure is the most effective, while injection pressure is the least important parameter for PP.
Vaatainen et al. [10] investigated the effect of the injection moulding parameters on the visual quality of mouldings using the Taguchi method. They focused on the shrinkage with three more Quality characteristics: weight, weld lines and sink marks. They were able to optimize many quality characteristics with very few experiments , which could lead to cost saving. Mohd. Muktar Alam, Deepak Kumar [11] ,in his paper determined optimal injection moulding condition for minimum shrinkage by the DOE technique of Taguchi methods. Packing pressure was found the most effective factor for PP followed by packing time, injection pressure and melt temperature. Gang XU, Fangbao DENG [12] in his study presented an innovative neural network-based quality prediction system for a plastic injection moulding process. The particle swarm optimization algorithm (PSO) is analyzed and an adaptive parameter-adjusting PSO algorithm based on velocity information (APSO-VI) is put forward. Experimental results show that APSO-VINN can better predict the product quality (volume shrinkage and weight) and can likely be used for various practical applications.

From the literature review, it can be concluded that, in order to minimize such defects in plastic injection moulding, design of experiment by Taguchi method can be applied and is considered suitable by many researchers. In experimental design, there are many variable factors that affect the functional characteristics of the product. Design parameter values that minimize the effect of noise factors on the product's quality are to be determined. In order to find optimum levels, fractional factorial designs using orthogonal arrays are used. In this way, an optimal set of process conditions can be obtained from very few experiments.

II. TAGUCHI TECHNIQUE

Taguchi technique [13] recommends to use orthogonal array experiments. It is used to optimize the performance characteristics within the combination of design parameters.

In the product/process design of Taguchi, there are basically three steps involved:-

i) System Design: selection of a system for a given objective function.

ii) Parameter Design: to find the optimum combinations of the process conditions for improving performance

characteristics.

iii)Tolerance Design: determination of tolerance around each parameter level.

Taguchi method uses signal-to-noise (S/N) ratio which reflects both the average and the variation of the quality characteristics. It is a measure of performance aimed at developing products and processes insensitive to noise factors.

Types of S/N ratio: <u>Larger- the- better:</u>
$S/N = -10 \log_{10}(1/n \Sigma 1/y_i^2)$

where, i=1 to n , n = no. of replications applied to the problems where maximization of quality characteristics of interest is needed.
<u>Smaller- the- better :</u>
$S/N = -10 \log_{10}(1/n \Sigma y_i^2)$

It is used where minimization of the characteristics is intended <u>Nominal-the-best :</u>

$S/N = -10 \log_{10} [\mu^2 / \sigma^2]$
where μ = mean , σ = standard deviation

It is used where one tries to minimize the mean squared error around a specific target value. Adjusting the mean to the target by any method renders the problem to a constrained optimization problem.

III. EXPERIMENTAL STUDY

A. *Materials*:

The input parameters selected are meting temperature, injection pressure, refilling pressure and cooling time. Shrinkage is selected as output.

The material selected is LDPE-16MA-400. Properties of LDPE are mentioned in table 1. 16MA400 is an injection moulding grade film grade Low Density Polyethylene (LDPE) produced by high pressure tubular process. The high melt flow index makes it ideal for moulding of very thin, intricate and large items having adequate mechanical properties. This grade is also an ideal choice for making master batches with higher loading.

Table 1: Properties of LDPE

Property	Unit	Typical Value
Density (23 ^{o}C)	g/cm^3	0.918
Melt flow index	g /10 min	30
Tensile strength at Yield	MPa	10
Elongation at Yield	%	40
Flexural Modulus	MPa	140

B. *Injection Moulding Process*:-

The part was injection moulded using a 100-ton injection moulding machine (Polyplast).

C. *Experimental Design:-*

Three levels of processing parameters and L9 orthogonal array are selected. The process parameters and levels are shown in table 2 and L9 orthogonal array is shown in table 3.

Table 2: The process parameters and levels

Sr. No.	Factors	Level 1	Level 2	Level 3
1	Melting Temperature, A (^{o}C)	190	200	210
2	Injection pressure, B (MPa)	55	60	70
3	Refilling pressure, C (MPa)	75	80	85
4	Cooling time, D (s)	7	9	11

Table 3: The L9 Orthogonal array

Sr. No.	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3

5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

D. ***Shrinkage measurement*****:-**

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

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

Here, D_m is mould dimension , D_p is part dimension and S is the shrinkage

IV. RESULTS AND DISCUSSION

Experimental result for LDPE is given in table 4. In this study lower value of shrinkage behavior is expected to be obtained. Thus, for S/N ratio characteristic the lower-the-better is applied in the analysis of experimental result, which is given below in table 4.

Table 4: Shrinkage values for LDPE

Melting Temperature, (^{o}C)	Injection pressure, (MPa)	Refilling pressure, (MPa)	Cooling time, (s)	Shrinkage (%) LDPE
190	55	75	7	1.575
190	60	80	9	1.50
190	70	85	11	1.25
200	55	80	11	1.437
200	60	85	7	1.50
200	70	75	9	1.625
210	55	85	9	1.375
210	60	75	11	1.40
210	70	80	7	1.78

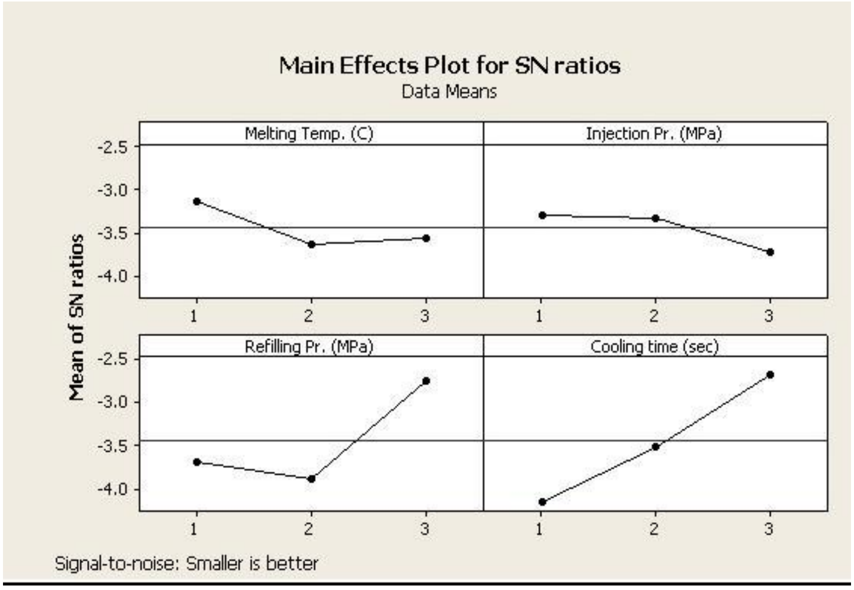
Table 5: The response table for S/N ratio for LDPE

Sr. No.	Melting Temperature, A (^{o}C)	Injection pressure, B (MPa)	Refilling pressure, C (MPa)	Cooling time, D (s)
Level 1	-3.135	-3.287	-3.695	-4.159
Level 2	-3.629	-3.322	-3.893	-3.502
Level 3	-3.566	-3.721	-2.742	-2.670
Delta	0.494	0.434	1.151	1.489
Rank	3	4	2	1

The response table of the S/N ratio is given in table 5. The best set of combination parameter can be determined by selecting the level with highest value for each factor. The optimal process parameter combination for LDPE is A1, B1, C3, D3.

The Delta value given in the table 5 denotes as to which factor is the most significant for shrinkage of LDPE moulding. Cooling time was found to be most effective factor for LDPE followed by refilling pressure. Injection pressure was found to be the least effective factor.

From the given data in table 5, S/N ratio response diagram was drawn and is shown in fig.1. The highest S/N ratio for each factor (see fig.1) gave the optimal process condition which corresponds to melting temperature of 190 ^{o}C, injection pressure of 55 MPa, refilling pressure of 85 MPa and cooling time of 11 sec.



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V. CONCLUSION

Taguchi method is used to investigate the effects of melting temperature, injection pressure, refilling pressure and cooling time on the shrinkage of LDPE. S/N ratios were used for determining the optimum combinations of the process conditions for shrinkage. The result showed that melting temperature of 190 ^{o}C, injection pressure of 55 MPa, refilling pressure of 85 MPa and cooling time of 11 sec. gave minimum shrinkage for LDPE. Cooling time was found to be most effective factor for LDPE followed by refilling pressure. Injection pressure was found to be the least effective factor. From the findings, it can be stated that Taguchi method is a powerful tool for evaluating the defect of shrinkage in the plastic injection moulding.

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