



Optimization of Injection Moulding Process Parameters in the Moulding of High Density Polyethylene (HDPE)

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ABSTRACT: In this study, optimal injection moulding conditions for minimum shrinkage during moulding of High Density Polyethylene (HDPE) were obtained by Taguchi method. The result showed that melting temperature of 190°C, injection pressure of 55 MPa, refilling pressure of 85 MPa and cooling time of 11 seconds gave minimum shrinkage for High Density Polyethylene. Cooling time was found to be the factor with most significant effect on the shrinkage of High Density Polyethylene followed by refilling pressure. Injection pressure was found to be the least effective factor.

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Injection moulding is a very complex process and its process variable like barrel (melt) temperature, injection pressure, the material flow rate, mould temperature and flow pattern usually interact between themselves and with the polymer properties to influence the solid properties of the moulded products (Osarenmwinda and Olodu, 2015). Injection moulding is a manufacturing process for producing parts by injecting material into a mould (Rosato *et al.*, 2000). Injection moulding can be performed with a host of materials, including metals, glasses, elastomers, confections, and most commonly thermoplastic and thermosetting polymers (Pötsch and Michaeli, 1995). 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 mould maker (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 (Brydson, 1995). Injection moulded parts must be very carefully designed to facilitate the moulding process. The material used for the part, the desired shape and 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 cause dimensional changes in the part, and it can be minimized by setting optimal process parameters on injection moulding machine (James Anderson *et al.*, 2014). Huang and Tai [2001] 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 (2010) utilized Taguchi method to optimize shrinkage of plastic, Polypropylene (PP) and Polystyrene (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 *et al* (2015) 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 and speed of mould, the DVD moulding cycle time can be reduced. He concluded that cooling time and hold time are also effective parameters to reduce cycle time (Kothari, 2016).

Alireza Akbarzadeh and Mohammad Sadeghi (2011) studied the relationship between input and output of the process using ANOVA. They considered four input parameters such as melting temperature, packing pressure, packing time and injection time and found that the packing pressure is the most effective, while injection pressure is the least

important parameter for Polypropylene (PP). Vaatainen *et al.*, (2016) 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 and Deepak Kumar (2013) in their paper determined optimal injection moulding condition for minimum shrinkage by the DOE technique of Taguchi methods. Packing pressure was found to be the most effective factor for Polypropylene (PP) followed by packing time, injection pressure and melt temperature. Gang *et al* (2011) in their study presented an innovative neural network-based quality prediction system for a plastic injection moulding process.

The particle swarm optimization algorithm (PSO) was analyzed and an adaptive parameter-adjusting PSO algorithm based on velocity information (APSO-VI) was 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 shrinkage 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. This study is to determine the optimal injection moulding process parameters in the moulding of High Density Polyethylene in order to reduce the shrinkage defect to the barest minimum.

MATERIALS AND METHODS

Materials: The input parameters selected are melting temperature, injection pressure, refilling pressure and cooling time. Shrinkage is selected as output. The material selected is HDPE-16MA-400. Properties of HDPE are shown in Table 1. 16MA-400 is an injection moulding grade film for High Density Polyethylene (HDPE) 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 High Density Polyethylene (HDPE)

Property	Unit	Typical Value
Density (24°C)	g/cm ³	0.918
Melt Flow Index	g/10 minutes	30
Tensile Strength at Yield	MPa	10
Elongation at Yield	%	40
Flexural Modulus	MPa	140

The following methods were used in this study:

Injection Moulding: Process: The part was injection moulded using a 100-ton injection moulding machine (Polyplast) (Osarenmwinda and Olodu, 2015)

Taguchi Technique: Taguchi technique is recommended to use orthogonal array experiments. It is used to optimize the performance characteristics within the combination of design parameters (Taguchi, 1990). 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:

(i) *Larger-the-better:* $\frac{S}{N} = -10 \log_{10} \left(\frac{1}{n} \sum \frac{1}{y_i^2} \right)$, where $i=1$ to n , n = Number of replications applied to the problems where maximization of quality characteristics of interest is needed.

(ii) *Smaller-the-better:* $\frac{S}{N} = -10 \log_{10} \left(\frac{1}{n} \sum \frac{1}{y_i^2} \right)$. It is used where minimization of the characteristics is intended.

(iii) *Nominal-the-best:* $\frac{S}{N} = -10 \log_{10} \left[\frac{\mu^2}{\sigma^2} \right]$ 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.

Experimental Design: Three levels of processing parameters and L9 orthogonal array were selected. The process parameters and levels are shown in Table 2 and L9 orthogonal array is shown in Table 3.

Shrinkage measurement: It is the difference between the size of mould cavity and size of finished part divided by size of the mould. $S = \frac{D_m - D_p}{D_m} \times 100$. Here, D_m is mould dimension, D_p is part dimension and S is the shrinkage.

Table 2: The Process Parameters and Levels

Serial Number	Factors	Level 1	Level 2	Level 3
1	Melting Temperature, A (°C)	190	200	210
2	Injection Pressure, B (MPa)	55	60	70
3	Refilling Pressure, C (MPa)	75	80	85
4	Cooling Time, D	7	9	11

Table 3: The L9 Orthogonal Array

Serial Number	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

RESULTS AND DISCUSSION

Experimental result for High Density Polyethylene (HDPE) is shown 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 shown in Table 4.

Table 4: Shrinkage Value for High Density Polyethylene. (HDPE)

Melting Temperature (°C)	Injection Pressure (MPa)	Refilling Pressure (MPa)	Cooling Time (s)	Shrinkage Percentage (%) HDPE
190	55	75	7	1.575
190	60	80	9	1.500
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 High Density Polyethylene (HDPE)

Serial Number	Melting Temperature, A (°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 shown 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 High Density Polyethylene (HDPE) is A1, B1, C3, and D3. The Delta value given in Table 5 shows the factor that is most significant for shrinkage of High Density Polyethylene (HDPE) moulding. Cooling time with a Delta value 1.489 was found to be the factor with most significant effect on the shrinkage of High Density Polyethylene (HDPE) followed by refilling pressure with Delta value of 1.151 (Table 5). Injection pressure was found to be the least effective factor with Delta value of 0.434. S/N ratio response diagram was drawn and is shown in Figure 1. The highest S/N ratio for each factor gave the optimal process condition which corresponds to melting temperature of 190°C, injection pressure of 70 MPa, refilling pressure of 85 MPa and cooling time of 11 seconds (Figure 1).

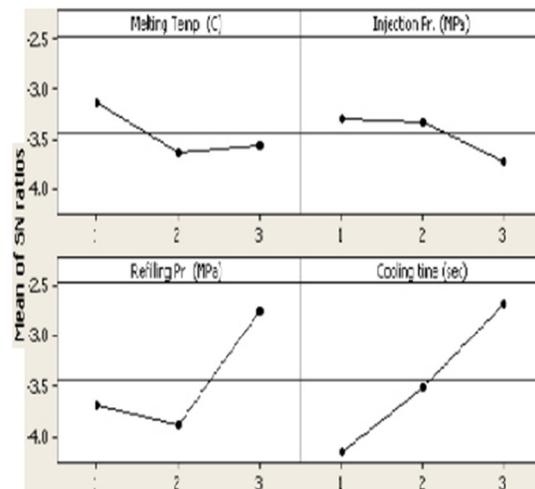


Fig 1: Plot of Main Effects for S/N ratio

Conclusion: Taguchi method was used to determine the optimum combinations of the process conditions for shrinkage of HDPE material. The result showed that melting temperature of 190°C, injection pressure of 70 MPa, refilling pressure of 85 MPa and cooling time of 11 seconds gave minimum shrinkage. Cooling time was found to be most effective factor followed by refilling pressure. Injection pressure was found to be the least effective factor. It is hoped that this study will assist polymer engineers and researchers to produce high quality and defect free plastic products which will ultimately lead to high productivity in the plastic industries.

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