The Effect of Processing Parameters on Density and Weight during the Injection Molding Process

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Received: 24 February 2025 | Revised: 5 April 2025 | Accepted: 9 April 2025

DOI: https://doi.org/10.48084/etasr.10702

ABSTRACT

The Injection Molding Process (IMP) produces a mass amount of plastic products with high complex shape, low cost, and feasible machinability. However, there are certain problems during IMP linked to product weight and density, affecting the stability and harness of the product, and thus its main quality. This paper examines the influence of injection molding parameters on plastic product density and weight during IMP. The material used for the present study is Medium Density Polyethylene (MDPE) with distinguished properties, namely chemical resistance, low cost, and easy processing. The experiment is designed based on the Taguchi method along with the crucial injection molding parameters, including melt temperature (*A*), packing pressure (*B*), packing time (*C*), cooling time (*D*), and mold temperature (*E*). The experiments are carried out using Moldex3D software. The Analysis of Variance (ANOVA) provides the results of the aforementioned parameters' influence on product density and weight. It is demonstrated that packing time (*C*), cooling time (*D*), and mold temperature (*E*) are the main factors influencing density, while melt temperature (*A*) and packing pressure (*B*) are the main factors affecting weight.

Keywords-IMP; processing parameters; optimization; ANOVA; Taguchi; MDPE

I. INTRODUCTION

IMP constitutes a mass production method of plastic products with high precision, complex shape, low cost, and feasible machinability [1]. Nevertheless, there are some defects during IMP, such as weld line, shrinkage, warpage, and others related to product weight and density [2, 3]. These issues impact the quality of the final injection molded products in terms of thickness, length, hardness, and strength [4]. In IMP, molten polymer is injected into a desired cavity under high pressure and then solidified by cooling to form a plastic product. The plastic material is subjected to high temperature and pressure, which affect its mechanical behavior by causing shear deformation and residual stress, and thus resulting in poor quality of the molded part [5, 6]. There are three basic stages during a molding cycle, including filling, post-filling, and mold opening [7]. Important processing parameters, such as melt temperature (*A*), packing pressure (*B*), packing time (*C*), cooling time (*D*), and mold temperature (*E*), are carefully set to work closely together in a very complicated IMP cycle to produce high product quality. The former guarantee the sustainable production of an IMP product in conjunction with processing parameters that play a crucial role in accomplishing the high quality of the final product [8, 9]. However, it is difficult to compile a set of processing parameters for IPM to achieve the desired part properties and product quality during fabrication. In practice, molding conditions are usually taken from IPM materials or handbooks with the limitations of high cost, time consumption, and dependence on the experience of machine operators [10]. Computer-Aided Engineering (CAE) has significant benefits on the design and manufacturing processes in the injection molding industry, such as increasing quality and reducing cost by using simulation and analysis techniques [11]. The combination method of simulation and data analysis is an effective way to reduce product defects during IMP [12]. The material used for the current study is MDPE, a type of Polyethylene (PE) with chemical resistance, low cost, and easy processing [13], which is widely utilized in household appliances, packaging, electronics, pipes, and industrial applications [14-16]. Several studies have focused on methods and techniques to control product weight during IMP, and hence improve product quality. These involve using regression models and pressure sensors to estimate product weight, developing neural networks to predict part weight, and deploying the ultrasonic technique to measure product density [17-20]. The Taguchi method is an effective technique for solving statistical problems and arranging a series of experiments with cost effectiveness, time reduction, and minimal testing. It reduces warpage and shrinkage in the IMP system [21], improves the surface roughness of the product during the electrical discharge machining process [22], optimizes the processing parameters during the rolling process of the rubber sheet [23], and examines the effect of processing factors on the surface harness of the product during the turning process [24].

II. EXPERIMENT PROCEDURE

The product utilized in the present study is MDPE, with a melting temperature of 120-125 °C, a glass transition temperature of about 110 °C, and a melt flow index of about 4 g/10 min [25]. The injection molding machine employed is the SE180EV-A C450M model, with a maximum clamp force of 184 Tf, an injection stroke of 450 mm, and a maximum injection pressure of 209 MPa. As shown in Figure 1, the dimensions of the product are a maximum length of 189 mm, a thickness of 3.2 mm, and a maximum width of 19 mm. The component under consideration is produced using a two-platen mold.

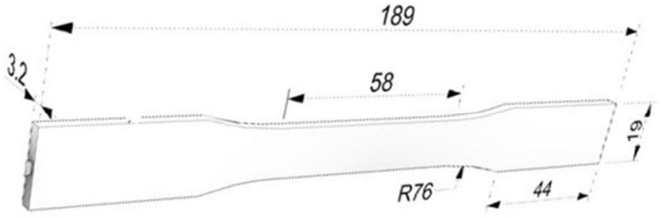

Fig. 1. The part for IMP.

As shown in Table I, IMP is based on input parameters, such as melt temperature (*A*), packing pressure (*B*), packing time (*C*), cooling time (*D*), and mold temperature (*E*), while density and weight values are obtained after the simulation and analysis process. The analysis revealed that the sample with the maximum weight and density values was identified as the optimal specimen. The IMP results in a product with high harness and strength, which corresponds to its high weight and density. To address this challenge, an optimization algorithm based on the Taguchi method is employed, with the objective of maximizing the desired properties [26, 27]:

$$\eta = -10 \times log_{10}\left[\frac{\left(\sum_{i=1}^{n}\frac{1}{y_i^2}\right)}{n}\right] \quad (1)$$

where η is the Signal-to-Noise (S/N) ratio and y_i is the value of the ith variable.

TABLE I. INPUT PARAMETERS FOR IMP

Code	MDPE	Level			Units
A	Melt temperature	200	210	220	°C
B	Pack Pressure	70	85	100	MPa
C	Packing time	3	7	11	s
D	Cooling time	5	9	13	s
E	Mold temperature	30	50	70	°C

Table II presents the experimental design, which is based on an orthogonal array with three levels for each factor. As presented in Figure 2, the layout has been configured for the IMP. Product simulation was carried out using Moldex3D software. The mesh type utilized is solid, with a total of 150,743 elements.

III. RESULTS AND DISCUSSION

Table III outlines the results of the response values for density and weight, with respect to the experiments, which used different sets of input parameters. Figure 3 illustrates the density results analyzed by implementing a Moldex3D software with the maximum density of 1.011 g/cc. Figure 4 shows the weight result analyzed using a Moldex3D software.

TABLE II. ORTHOGONAL ARRAY

Run	*A* (°C)	*B* (MPa)	*C* (s)	*D* (s)	*E* (°C)
1	200	70	3	5	30
2	200	70	3	5	50
3	200	70	3	5	70
4	200	85	7	9	30
5	200	85	7	9	50
6	200	85	7	9	70
7	200	100	11	13	30
8	200	100	11	13	50
9	200	100	11	13	70
10	210	70	7	13	30
11	210	70	7	13	50
12	210	70	7	13	70
13	210	85	11	5	30
14	210	85	11	5	50
15	210	85	11	5	70
16	210	100	3	9	30
17	210	100	3	9	50
18	210	100	3	9	70
19	220	70	11	9	30
20	220	70	11	9	50
21	220	70	11	9	70
22	220	85	3	13	30
23	220	85	3	13	50
24	220	85	3	13	70
25	220	100	7	5	30
26	220	100	7	5	50
27	220	100	7	5	70

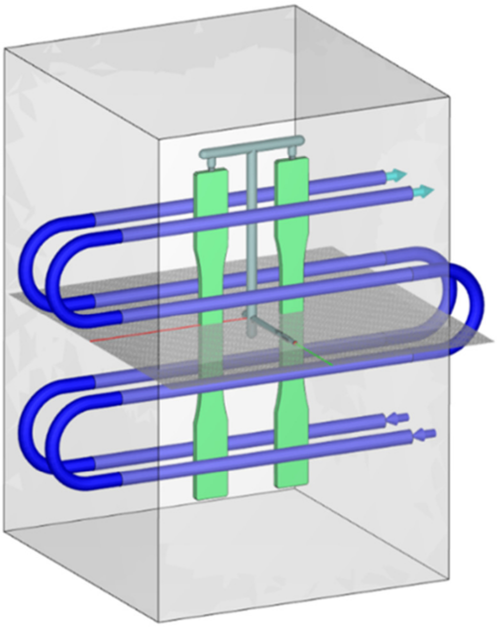

Fig. 2. Layout set up for IMP.

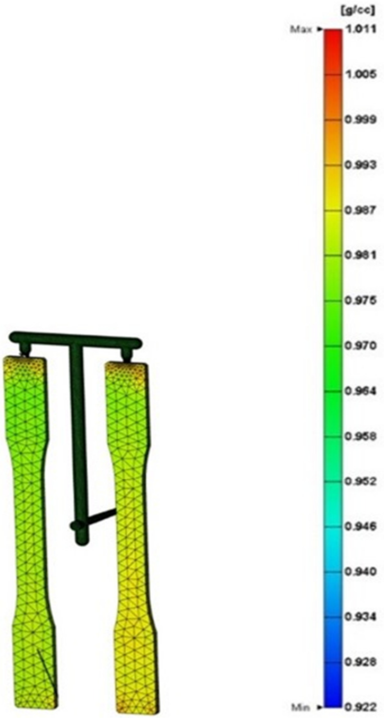

Fig. 3. Density results after simulation with Moldex3D.

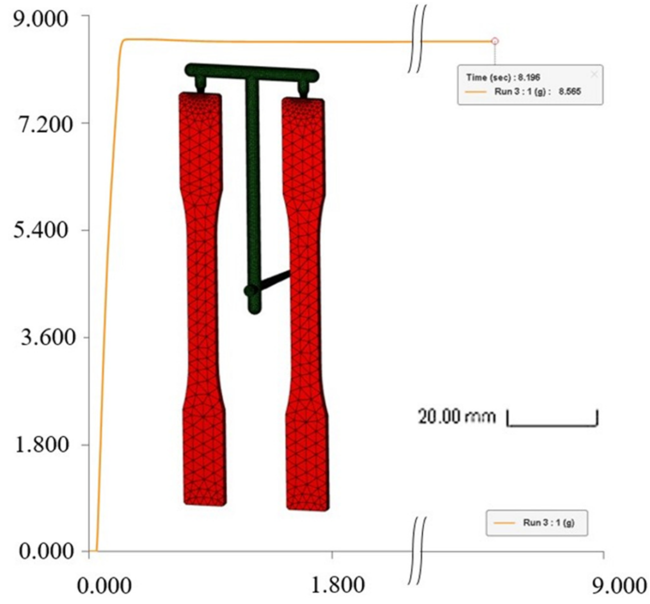

Fig. 4. Weight results after simulation with Moldex3D.

As depicted in Table IV, the S/N ratio results are derived using (1), while Table V presents the response values for the S/N ratios in terms of density. The results demonstrate that the variation and the impact levels of the factors on density are associated with the influence levels of *C-D-E-B-A*. Figure 5 presents the primary effects of the processing factors on product density, indicating that the optimal processing parameters for achieving the maximum density are *A* of 220 ^{o}C *B* of 85 MPa, *C* of 11 s, *D* of 13s, and *E* of 30 ^{o}C.

TABLE III. DENSITY AND PART WEIGHT MEASUREMENT RESULTS

Run	***A*** **(°C)**	***B*** **(MPa)**	***C*** **(s)**	***D*** **(s)**	***E*** **(°C)**	**Density (g/cc)**	**Weight (g)**
1	200	70	3	5	30	1.011	17.124
2	200	70	3	5	50	1.011	17.116
3	200	70	3	5	70	1.005	17.098
4	200	85	7	9	30	1.052	17.196
5	200	85	7	9	50	1.046	17.200
6	200	85	7	9	70	1.031	17.198
7	200	100	11	13	30	1.075	17.262
8	200	100	11	13	50	1.058	17.274
9	200	100	11	13	70	1.048	17.270
10	210	70	7	13	30	1.069	17.076
11	210	70	7	13	50	1.060	17.056
12	210	70	7	13	70	1.043	17.034
13	210	85	11	5	30	1.053	17.136
14	210	85	11	5	50	1.047	17.146
15	210	85	11	5	70	1.031	17.144
16	210	100	3	9	30	1.026	17.198
17	210	100	3	9	50	1.028	17.218
18	210	100	3	9	70	1.015	17.098
19	220	70	11	9	30	1.072	16.994
20	220	70	11	9	50	1.061	16.992
21	220	70	11	9	70	1.046	16.958
22	220	85	3	13	30	1.053	17.074
23	220	85	3	13	50	1.048	17.072
24	220	85	3	13	70	1.030	17.048
25	220	100	7	5	30	1.027	17.150
26	220	100	7	5	50	1.029	17.170
27	220	100	7	5	70	1.014	17.210

TABLE IV. S/N RATIO FOR EACH RESPONSE TO DENSITY AND WEIGHT

Run	**A (°C)**	**B (MPa)**	**C (s)**	**D (s)**	**E (°C)**	**Density (g/cc)**	**Weight (g)**	**Density (S/N)**	**Weight (S/N)**
1	200	70	3	5	30	1.011	17.124	0.095	24.672
2	200	70	3	5	50	1.011	17.116	0.095	24.668
3	200	70	3	5	70	1.005	17.098	0.043	24.659
4	200	85	7	9	30	1.052	17.196	0.440	24.709
5	200	85	7	9	50	1.046	17.200	0.391	24.711
6	200	85	7	9	70	1.031	17.198	0.265	24.710
7	200	100	11	13	30	1.075	17.262	0.628	24.742
8	200	100	11	13	50	1.058	17.274	0.490	24.748
9	200	100	11	13	70	1.048	17.270	0.407	24.746
10	210	70	7	13	30	1.069	17.076	0.580	24.648
11	210	70	7	13	50	1.060	17.056	0.506	24.638
12	210	70	7	13	70	1.043	17.034	0.366	24.626
13	210	85	11	5	30	1.053	17.136	0.449	24.678
14	210	85	11	5	50	1.047	17.146	0.399	24.683
15	210	85	11	5	70	1.031	17.144	0.265	24.682
16	210	100	3	9	30	1.026	17.198	0.223	24.710
17	210	100	3	9	50	1.028	17.218	0.240	24.720
18	210	100	3	9	70	1.015	17.098	0.129	24.659
19	220	70	11	9	30	1.072	16.994	0.604	24.606
20	220	70	11	9	50	1.061	16.992	0.514	24.605
21	220	70	11	9	70	1.046	16.958	0.391	24.588
22	220	85	3	13	30	1.053	17.074	0.449	24.647
23	220	85	3	13	50	1.048	17.072	0.407	24.646
24	220	85	3	13	70	1.030	17.048	0.257	24.634
25	220	100	7	5	30	1.027	17.150	0.231	24.685
26	220	100	7	5	50	1.029	17.170	0.248	24.695
27	220	100	7	5	70	1.014	17.210	0.121	24.716

TABLE V. S/N RATIO RESPONSE TO DENSITY

Level	A	B	C	D	E
1	0.3172	0.3548	0.2153	0.2163	0.4109
2	0.3507	0.369	0.3498	0.3552	0.3656
3	0.358	0.302	0.4607	0.4543	0.2493
Delta	0.0408	0.0671	0.2454	0.2381	0.1616
Rank	5	4	1	2	3

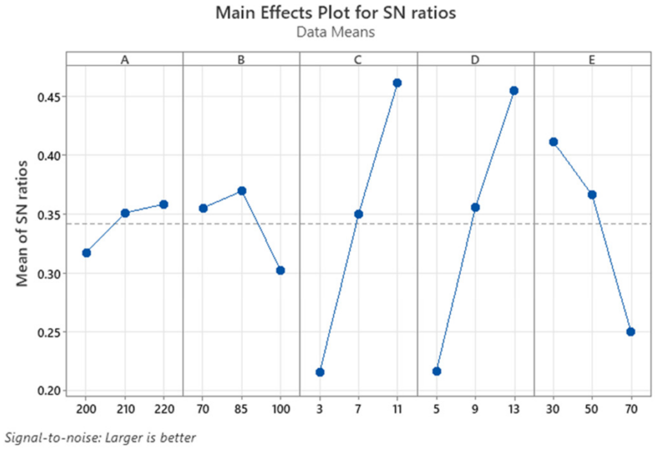

Fig. 5. The main effects of the processing factors on density.

Table VI shows the factors' influence on the weight, according to level *B-A-D-C-E,* and Figure 6 presents the primary effect analysis of the processing factors on the weight. The findings indicate that the optimal parameter configuration for achieving the maximum weight is *A* of 200 °C, *B* of 100 MPa, *C* of 7 s, *D* of 5 s, and *E* of 50 °C.

TABLE VI. S/N RATIO RESPONSE TO WEIGHT

Level	*A*	*B*	*C*	*D*	*E*
1	24.71	24.63	24.67	24.68	24.68
2	24.67	24.68	24.68	24.67	24.68
3	24.65	24.71	24.68	24.67	24.67
Delta	0.06	0.08	0.01	0.01	0.01
Rank	2	1	4	3	5

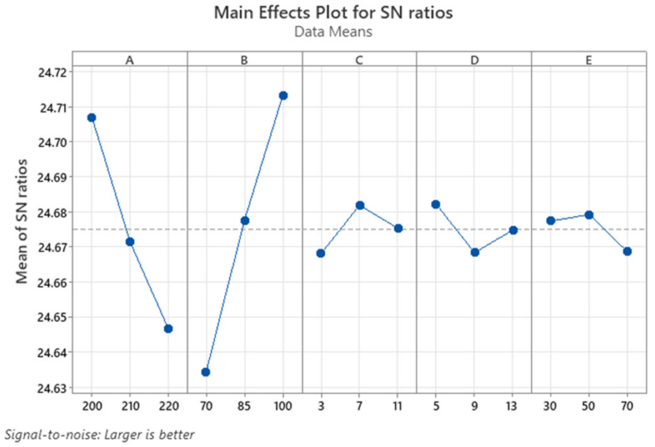

Fig. 6. The main effects of the processing factors on weight.

Table VII presents the ANOVA performed on density parameters. The results reveal the extent to which the factors influence response. An A P-value less than 0.05 indicates a significant influence of the parameter. The analysis demonstrates that the parameters *B*, *C*, *D*, and *E* exert a substantial influence on the response. The model exhibits a commendable level of accuracy, with a percentage of 97.22%. The influence percentage of the processing parameter on density is shown, with the *C* factor exhibiting the highest influence at 38.56%, followed by the *D* factor at 36.52%, while *E*, *B*, and *A* factors follow, with their respective influences of 17.74%, 3.19%, and 1.21%.

TABLE VII. ANOVA FOR DENSITY

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	*F*-Value	*P*-Value
A	2	0.008523	1.21%	0.008523	0.004262	3.48	0.056
B	2	0.022486	3.19%	0.022486	0.011243	9.19	0.002
C	2	0.271818	38.56%	0.271818	0.135909	111.07	0
D	2	0.257396	36.52%	0.257396	0.128698	105.18	0
E	2	0.125049	17.74%	0.125049	0.062525	51.1	0
Error	16	0.019578	2.78%	0.019578	0.001224		
Total	26	0.70485	100.00%				
R-sq = 97.22%							

As displayed in Table VIII, an ANOVA was conducted on the processing parameters associated with weight. An A *P*-value less than 0.05 indicates a significant influence of the parameter. The analysis suggests that the *A* and *B* parameters exert a substantial influence on the response. The model demonstrates a high degree of reliability, with an accuracy of 94.54%. The influence percentage of parameters on the weight is shown, with the *B* factor reaching 56.69%, the *A* factor 33.29%, and *C*, *D* and *E* factors corresponding to 1.72%, 1.71%, and 1.14%, respectively.

TABLE VIII. ANOVA FOR WEIGHT

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	*F*-Value	*P*-Value
A	2	0.016542	33.29%	0.016542	0.008271	48.82	0
B	2	0.028169	56.69%	0.028169	0.014085	83.13	0
C	2	0.000848	1.71%	0.000848	0.000424	2.5	0.113
D	2	0.000855	1.72%	0.000855	0.000427	2.52	0.112
E	2	0.000564	1.14%	0.000564	0.000282	1.66	0.22
Error	16	0.002711	5.46%	0.002711	0.000169		
Total	26	0.04969	100.00%				
R-sq = 94.54%							

IV. CONCLUSIONS

The Injection Molding Process (IMP) produces a high volume of plastic products with intricate shapes, low cost, and machine-friendly properties. However, the process is not without its challenges, as it can give rise to issues that affect the quality of the final product, particularly regarding its strength and hardness. These issues are contingent on the weight and density of the component that is injection molded. This study aims to examine the influence of injection molding parameters on the density and weight of plastic products. The Taguchi method and Analysis of Variance (ANOVA) have been used along with the main injection molding parameters. The method constitutes a low-cost and effective technique, applicable for solving engineering problems, such as increasing the weight of the product during IMP. The results indicate that the packing time (*C*), cooling time (*D*), and mold temperature (*E*) parameters are the primary influencing factors on density. Conversely, the melt temperature (*A*) and packing pressure (*B*) emerged as the predominant factors influencing weight. The study's findings reveal that the impact levels of the processing factors on density are: *C* at 38.56%, *D* at 36.52%, *E* at 17.74%, *B* at 3.19%, and finally *A* at 1.21%. The optimal parameters for achieving maximum density are: *A* at 220 °C, *B* at 85 MPa, *C* at 11 s, *D* at 13 s, and *E* at 30 °C. The influence levels of the factors on the weight are *B-A-D-C-E*, equivalent to 56.69%, 33.29%, 1.72%, 1.71%, and 1.14%, respectively. The optimal parameters for achieving maximum weight are: *A* of 200 °C, *B* of 100 MPa, *C* of 7 s, *D* of 5 s, and *E* of 50 °C.

ACKNOWLEDGMENT

This work was sponsored by Hanoi University of Industry, Hanoi, Vietnam.

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