Effect of Factors on Compression Force for Traffic Cone Production by Rotational Molding Process

Pongthorn Ruksorn and Siraprapha Deepradit

***Abstract*—The objective of this research was to study factors that affect the compression force for traffic cone production by a rotational molding process. A Box-Behnken design was used to examine traffic cone produced by a rotational molding machine with three control factors including temperature, molding time, and rotational level. The result showed that temperature significantly affected the compression force for traffic cone production by a rotational molding process. The appropriate parameters to maximize the compression force for traffic cone production were temperature at 230 degrees of Celsius, molding time at 13 minutes, and rotational level at 4 rounds per minute.**

***Keywords*—Traffic cone, Rotational molding, Design of experiment, Box-Behnken**

I. INTRODUCTION

Plastics are increasingly important on-demand in the manufacture of materials due to their significantly higher strength and stiffness. Polyethylene is used to produce products by injection molding, extrusion, and thermoforming operations [1]. Low density polyethylene (LDPE) is soft, flexible, and unbreakable which is widely used plastic, especially in wash bottles, general-purpose tubing, and small tanks. LDPE will dissolve slowly above 50 °C in hydrocarbons and higher aliphatic esters [2-5].

Rotational molding is one of the techniques frequently used for polymer process and it has been applied in various fields such as agriculture, storage tank, industrial equipment, material handling, and automobile industries. Linear low-density polyethylene (LLDPE) has the largest consumption in the rotational molding industry due to excellent thermal stability and good mechanical properties. Many previous researches have studied the foaming using LLDPE foams in rotational molding. Rumkumar et al. (2014) studied the impact strength of foamed LLDPE for the rotational molding process [6]. Greco et al. (2014) studied the use of a pultruded profile for the selective reinforcement of LLPDE components produced by rotational molding [7].

The research efforts in rotational molding were relatively investigated. Sari et al. (2019) have focused on the effect of plasma modification of polyethylene by rotational molding of natural fiber composites [8]. Rotational molding of polymer liners was studied by Murray et al. (2017) [9]. Few works have been conducted mathematical models in rotational molding. Hamidi et al. (2015) studied the surface tension model with a smoothed particle hydrodynamics method in reactive rotational molding [10]. A similar study has been conducted by Garg et al. (2019) on model predictive control for uni-axial rotational molding [11].

The traffic cone is a cone-shaped marker that is placed on the road to temporarily redirect traffic (as shown in Fig. 1.) fabricated by a rotational molding machine as shown in Fig. 2. Rotational molding is based on factors and their levels which affect the quality characteristic. The objective of this research was to study the factors and their levels that affect the compression force for traffic cone production by the rotational molding process.

Fig. 1. Traffic cone

Fig. 2. Rotational molding machine

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II. MATERIALS AND METHODS

A. Materials

The material in this study was carried out using linear low density polyethylene (LLDPE) of grade M9001RW/RWP having the density of 0.939 g/cm3 supplied by SCG ICO Polymers company limited, characterized by a melt index is equal to 32 (measured by ASTM D 1238) and a melting point is equal to 127 °C (measured by ASTM D 2117) as shown in Figure 3. The above-mentioned grade is recommended for large water tanks, material handling containers and other general rotational molded articles. Three control factors were investigated including temperature (A), molding time (B), and rotational level (C).

Fig. 3. Linear low density polyethylene (LLDPE) of grade M9001RW/RWP

B. Methods

First, this research studied the rotational molding process by a rotational machine. The temperature, molding time, and rotational level are tested for forming traffic cones. Second, a Box-Behnken design [12] was employed to collect data which was formed by combining 2^k factorials with incomplete block designs to find the factors and their levels that affect the compression force for traffic cone production by the rotational molding process. Third, the experiment plan was to divide the control factors into three levels as low (-1), medium (0), and high (+1) with three center points using summarized in TABLE I. Fourth, the experiment was run with two replicates. Consequently, the total number of runs was 30 samples to be used in this study as shown in TABLE II. The compression force was tested by the compression testing machine as shown in Fig. 4. The compression force values were calculated in this compression testing machine as shown in Fig. 5. Next, the assumptions of a normal distribution, zero average, constant variance, and independence were tested before analyzed the analysis of variance (ANOVA). If all assumptions were satisfied, the ANOVA was conducted. Then, the factors were indicated the significantly affected the compression force. Finally, the compression force equation is conducted and verified.

TABLE I: FACTORS AND THEIR LEVELS FOR BOX-BEHNKEN DESIGN

Factors	Level		
	Low (-1)	Medium (0)	High (+1)
Temperature; A (°C)	230	250	270
Molding time; B (min)	13	15	17
Rotational level; C (rpm)	4	5	6

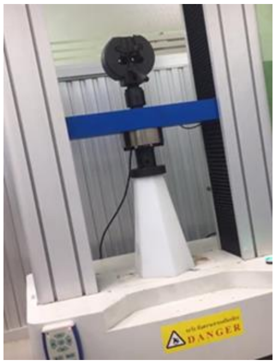

Fig. 4. Compression testing machine

TABLE II: BOX-BEHNKEN DESIGN REPLICATED TWICE WITH RANDOM RUN ORDER

Run Order	Standard Order	A (°C)	B (min)	C (rpm)	Compression Force (N)
1	9	250	13	4	12667.04
2	20	230	15	4	12842.54
3	17	270	13	5	11608.04
4	12	250	17	6	10849.92
5	14	250	15	5	10923.04
6	27	250	17	6	12475.54
7	13	250	15	5	10631.05
8	2	270	13	5	10921.04
9	11	250	13	6	11178.54
10	29	250	15	5	12573.54
11	16	230	13	5	13434.05
12	28	250	15	5	10673.04
13	25	250	17	4	11095.04
14	23	270	15	6	10118.32
15	30	250	15	5	10681.04
16	24	250	13	4	11965.54
17	6	270	15	4	11454.04
18	4	270	17	5	12007.54
19	7	230	15	6	11842.54
20	15	250	15	5	10697.04
21	26	250	13	6	11632.54
22	1	230	13	5	11094.04
23	18	230	17	5	11781.04
24	10	250	17	4	12305.04
25	21	270	15	4	11548.04
26	3	230	17	5	11687.78
27	22	230	15	6	11863.04
28	8	270	15	6	10044.03
29	5	230	15	4	11205.04
30	19	270	17	5	10473.03

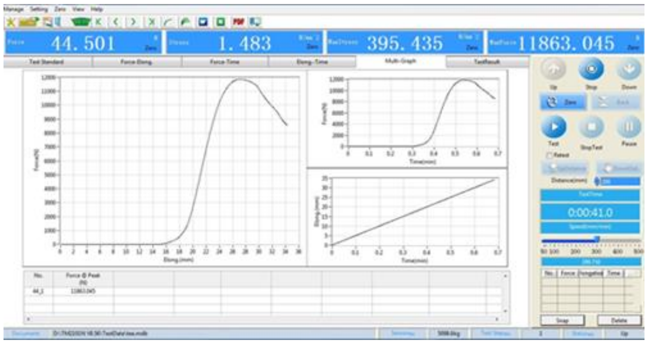

Fig. 5. Compression force value

Before the analysis of variance (ANOVA), it was necessary to verify the assumptions of residual including normal distribution, zero average, constant variance, and independence [12]. Minitab statistical software was used to check residual analysis.

After the assumptions of residual were confirmed, the hypothesis testing was analyzed for the main factor and the interaction factor.

(i) Hypothesis testing for the main factor

H_0: the main factor has no effect on the compression force

H_1: the main factor has an effect on the compression force

(ii) Hypothesis testing for the interaction factor

H_0: the interaction factor has no effect on the compression force

H_1: the interaction factor has an effect on the compression force

The null hypothesis will be rejected if the p-value is smaller than the significance level of 0.05 (95% confidence interval) [13].

III. RESULT AND DISCUSSION

The assumptions of residuals were tested by Minitab statistical software with a 95% confidence interval. The assumptions of a normal distribution, zero average, constant variance, and independence were analyzed, as shown in Fig.6. to Fig. 8.

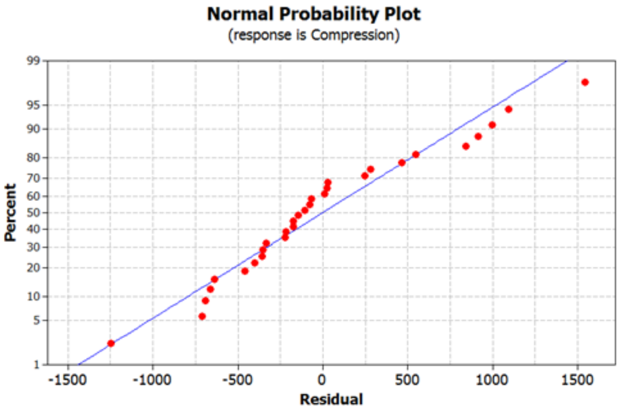

Fig. 6. Normal probability plot of residuals for the compression force

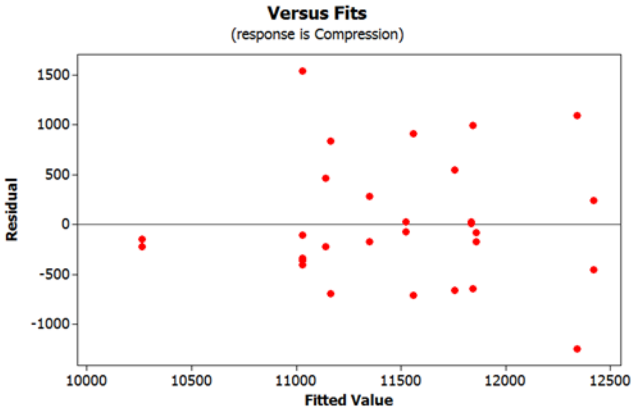

Fig. 7. Residuals versus fitted values for the compression force

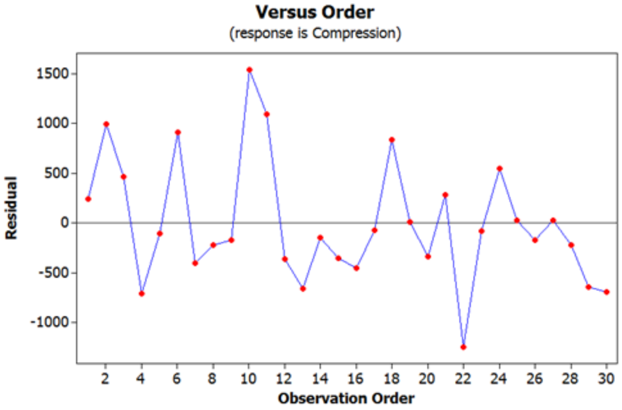

Fig. 8. The plot of residuals in time sequence for the compression force

The assumptions were tested. First, the normal probability plot of residual was a straight line, thus the normality assumption was satisfied. Second, the residuals were balanced and randomly distributed around the axis, thus the residuals were zero average and constant variance. Lastly, the residuals were not structured and randomly distributed around the axis, thus the residuals were independent.

After the four assumptions were satisfied, the ANOVA was conducted for the Box-Behnken design. The result from ANOVA was shown in TABLE III where df is the degrees of freedom; SS is the sum of squares; MS is the mean sum of squares; F is the F test statistic; A is temperature; B is the molding time; C is the rotational level, and P-value is the significant at p less than 0.05.

TABLE III: ANALYSIS OF VARIANCE FOR THE COMPRESSION FORCE

Source	df.	SS	MS	F	P-Value
Regression	9	8866305	985145	1.78	0.136
Linear	3	5407131	1802377	3.25	0.043
A	1	3587227	3587227	6.47	0.019*
B	1	208369	208369	0.38	0.547
C	1	1611535	1611535	2.91	0.104
Square	3	2170189	723396	1.30	0.301
A*A	1	66350	66350	0.12	0.733
B*B	1	1855321	1855321	3.35	0.082
C*C	1	425774	425774	0.77	0.391
Interaction	3	1288985	429662	0.77	0.522
A*B	1	127704	127704	0.23	0.637
A*C	1	779832	779832	1.41	0.250
B*C	1	381449	381449	0.69	0.417
Residual	20	11092343	554617		
Lack-of-Fit	3	273083	91028	0.14	0.933
Pure Error	17	10819260	636427		
Total	29	19958649			

The result in TABLE III indicates that temperature (A) significantly affected the compression force for traffic cone production by the rotational molding process since the p-value was smaller than the significance level of 0.05.

The lack-of-fit [13] was used to test the fit of the model. If the p-value is more than a significance level of 0.05, the statistical model accurately fits the data. The hypotheses were:

H_0: the model accurately fits the data

H_1: the model does not accurately fit the data

Thus, the p-value for lack of fit was 0.933 suggesting that this model adequately fit the data. The appropriation of the statistical model showed in (1).

$$\textit{Compression force} = 68919.5 - 111.5A - 5151.9B - 453.5C + 0.2A^2 + 125.3B^2 + 240.1C^2 + 3.2AB - 15.6AC + 109.2BC \quad (1)$$

The compression force equation was used to determine the appropriate parameters by response optimizer in Minitab statistical software as shown in Fig. 9.

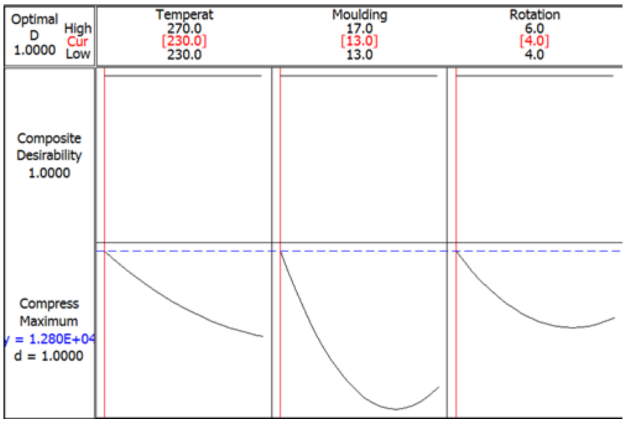

Fig. 9. Optimization plot for compression force

The optimization plot for the compression force indicates that the temperature (A), molding time (B), and rotational level (C) should be set 230 °C, 13 min, and 4 rpm, respectively, to maximize the compression force for traffic cone production. The compression force was 1.28 x 10^4 N, the composite desirability of 1.00. Besides, the compression force is verified and validated.

IV. CONCLUSION

This research proposed the design of experiments. This work impacts the factory perspective and helps to choose appropriate factors. The objective of this research was to study the effect of factors and their levels on the compression force for traffic cone production by the rotational molding process. The Box-Behnken design was used in this research. Based on the experimental results, the main conclusions were:

1. The temperature term was significant at p-value < 0.05, thus the temperature significantly affected the compression force for traffic cone production by the rotational molding process.
2. The appropriate parameters to maximize the compression force for traffic cone production were temperature (A) at 230 °C, molding time (B) at 13 min, and rotational level (C) at 4 rpm.

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