A Study of Parameter Affecting the Edge Crack Defect for Rubber Graphite Product

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Abstract — **The objectives of this research are to study the process parameters significantly affecting the edge crack defect and to determine the optimal condition providing the lowest quantity of the edge crack defects on extruded rubber graphite products. In this research, Design of Experiments was applied to study three factors including (i) screw speed, (ii) barrel temperature and (iii) head temperature (or die temperature) while the response variable is the quantity of edge crack defects on the rubber graphite product. The results of the experimental analysis showed that all three factors, significantly affected the quantity of edge crack defect. A Response Surface Methodology (RSM) technique was then applied to determine the optimal condition of the process parameters, which was found to be at the screw speed of 1.5 rpm, the barrel temperature of 65 ^oC, and the head temperature of 64.04 ^oC. The optimal condition of these process parameters significantly reduced the quantity of edge crack defect on the extruded rubber graphite product.**

***Keywords*— Rubber Extrusion, Design of Experiments (DOE), Response Surface Methodology (RSM)**

I. Introduction

Rubber is one of the most important materials in Thailand. Rubber is commonly available, highly useful and widely used in various applications such as household, medication, and industry. For this reason, research on rubber product manufacturing is greatly vital in developing the rubber product to compete in the worldwide market [1].

This research is related to a study of the extrusion process of a rubber graphite product, which is used as a seal in the suction roll. The production line of this rubber product consists of mixing, extrusion, vulcanization and finishing. After the rubber and its components are mixed, the rubber compound is then passed to the extrusion process, which is performed by a screw-type extruder. It is found that edge crack of the product is a major defect, which is commonly found on a edge of the product after the extrusion process.

Response Surface Methodology (RSM) is a collection of mathematical and statistical techniques, which are useful for modelling and analysing problems. The main objective of RSM is to optimize the process parameters to achieve the desired response. In most RSM modelling, the form of relationship between the response and the independent variables is unknown [2].

II. Objectives

The main objectives of this research are as follows:

(i) To study the process parameters that significantly affect the edge crack defect.

(ii) To determine the optimal condition of the process parameters providing the lowest quantity of the edge crack defects on the extruded rubber graphite product.

III. Experiment and Method

A. Introduction

Problem identification – edge crack problem

Response Variable – quantity of edge crack defects on the rubber graphite product measured by counting point by point at 4 edges on each piece of rubber graphite product dimensions 25x65x300 millimetres. Therefore, the unit of this variable was under the unit of point.

Factors identification – three process parameters were selected including (i) screw speed, (ii) barrel temperature and (iii) head temperature (or die temperature).

B. Experimental Method

This research consists of three steps as follows.

1. Screening and Curvature checking – A 2^k Full Factorial design with center points was employed to screen the parameters. Center points were also added to check the curvature (non-linear relationship) of the regression model whether the first-order modelling is enough or not. Levels of each parameter used in the experimental plan are summarized as shown in Table I.

TABLE I
PARAMETERS AND THEIR LEVELS USED IN A 2^K FULL FACTORIAL DESIGN WITH CENTER POINTS

Parameters	Unit	Levels		
		Low	Center Point	High
A: Screw Speed	rpm	1.5	2.5	3.5
B: Barrel Temperature	°C	55	60	65
C: Head temperature (or Die temperature)	°C	60	65	70

The experimental plan was performed by Minitab with 2 replicates and 4 center points resulting in the total runs of 20 as shown in Fig 1. In addition, the response in these experiments is the defect quantity as shown in the most right column in Fig 1.

Std Ord	Run Order	Center Pt	Blocks	Speed	Barrel	Head	Defect Quantit
10	1	1	1	3.5	55	60	
6	2	1	1	3.5	55	70	
7	3	1	1	1.5	65	70	
9	4	1	1	1.5	55	60	
2	5	1	1	3.5	55	60	
12	6	1	1	3.5	65	60	
1	7	1	1	1.5	55	60	
17	8	0	1	2.5	60	65	
20	9	0	1	2.5	60	65	
19	10	0	1	2.5	60	65	
16	11	1	1	3.5	65	70	
14	12	1	1	3.5	55	70	
4	13	1	1	3.5	65	60	
13	14	1	1	1.5	55	70	
11	15	1	1	1.5	65	60	
5	16	1	1	1.5	55	70	
3	17	1	1	1.5	65	60	
8	18	1	1	3.5	65	70	
15	19	1	1	1.5	65	70	
18	20	0	1	2.5	60	65	

Fig. 1 The experimental plan for the 2^k Full Factorial design with 4 center points from Minitab 16.

2. Central Composite Design - According to the results of the 2^k Full Factorial design with center points, it was found that all selected parameters, including screw speed, barrel temperature and head temperature, significantly affected the quantity of edge crack defect. In addition, the curvature of the model was also significant. The Face-centered Central Composite Design (CCD) [3] was then sequentially applied to create the second order regression model and to optimize the parameters to reduce the quantity of edge cracks. In the Face-centered Central Composite Design, the alpha levels (α = -1, +1) were added as the axial points to the previous 2^k Full Factorial design. Additional 6 points on the face center with 2 replicates, totally 12 additional runs, were added to the previous 2^k Full Factorial design. The additional runs can be found as block 2 in the experimental plan as shown in Fig. 2.

StdOrder	RunOrder	PtType	Blocks	speed	barrel	head
1	21	1	1	1.5	55	60
2	14	1	1	3.5	55	60
3	27	1	1	1.5	65	60
4	20	1	1	3.5	65	60
5	19	1	1	1.5	55	70
6	31	1	1	3.5	55	70
7	23	1	1	1.5	65	70
8	18	1	1	3.5	65	70
9	22	0	1	2.5	60	65
10	29	0	1	2.5	60	65
11	1	-1	2	1.5	60	65
12	9	-1	2	3.5	60	65
13	10	-1	2	2.5	55	65
14	8	-1	2	2.5	65	65
15	11	-1	2	2.5	60	60
16	5	-1	2	2.5	60	70
17	17	1	1	1.5	55	60
18	30	1	1	3.5	55	60
19	26	1	1	1.5	65	60
20	25	1	1	3.5	65	60
21	16	1	1	1.5	55	70
22	13	1	1	3.5	55	70
23	24	1	1	1.5	65	70
24	28	1	1	3.5	65	70
25	15	0	1	2.5	60	65
26	32	0	1	2.5	60	65
27	3	-1	2	1.5	60	65
28	12	-1	2	3.5	60	65
29	6	-1	2	2.5	55	65
30	7	-1	2	2.5	65	65
31	2	-1	2	2.5	60	60
32	4	-1	2	2.5	60	70

Fig. 2 The experimental plan of the Face-centered Central Composite Design from Minitab 16.

3. Confirmation runs – After the optimal condition was determined, 20 confirmation runs were performed at the optimal condition to validate the results of the experimental design. Because the data were not normally distributed, a sign test was then used to check the median value of the confirmation runs.

IV. RESULT AND DISCUSSION

The results can be divided into 3 sections as follows.

1. Results from the 2^k Full Factorial design

A. Model Adequacy Checking - The residual plots were used to check (i) normal distribution, (ii) variance stability and (iii) independence of the residuals to ensure that the conclusions from the experiments were accurate.

Normal distribution – According to the normal probability plot of the residuals as shown in Fig. 3, the residuals distributed in a straight line. Therefore, the residuals were normally distributed.

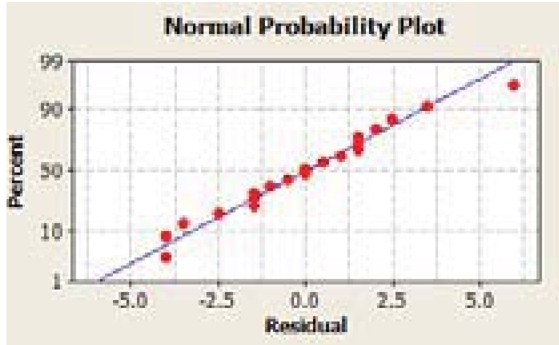

Fig. 3 The Normal Probability Plot of the residuals

Variance Stability – Referring to the residual plot versus fitted values as shown in Fig, 4. The residuals were randomly distributed without any particular shape. Therefore, the stability of variance was constant.

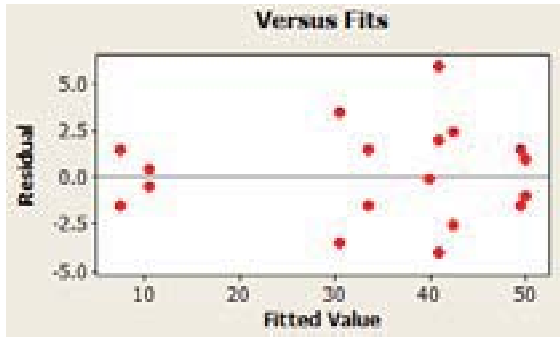

Fig. 4 The residual plot versus fits

Independence of the residuals – Referring to the residual plot versus observation orders as shown in Fig 5, it was found that the residuals were randomly distributed without any particular pattern. Therefore, the residuals were independent.

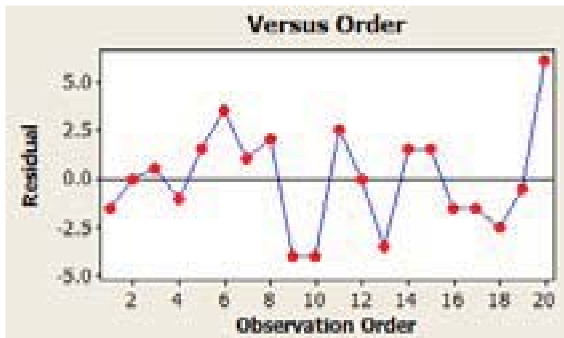

Fig. 5 The residual plot versus observation orders

B. Screening and Curvature checking

The experimental data were analyzed by using Minitab 16. The Analysis of Variance (ANOVA) table of the 2^k Full Factorial design with 2 replicates and 4 center points is summarized as shown in Table II.

TABLE II
THE ANOVA TABLE
FOR THE 2^K FULL FACTORIAL DESIGN

Analysis of Variance for Defect Quantity (coded units)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	3	2641.50	2641.50	880.50	77.40	0.000
Speed	1	930.25	930.25	930.25	81.86	0.000
Barrel	1	1681.00	1681.00	1681.00	147.93	0.000
Head	1	30.25	30.25	30.25	2.66	0.131
2-Way Interactions	3	1084.50	1084.50	361.50	31.81	0.000
Speed*Barrel	1	600.25	600.25	600.25	52.82	0.000
Speed*Head	1	64.00	64.00	64.00	5.63	0.037
Barrel*Head	1	420.25	420.25	420.25	36.98	0.000
3-Way Interactions	1	1.00	1.00	1.00	0.09	0.772
Speed*Barrel*Head	1	1.00	1.00	1.00	0.09	0.772
Curvature	1	204.00	204.00	204.00	18.02	0.001
Residual Error	11	125.00	125.00	11.36		
Pure Error	11	125.00	125.00	11.36		

According to the statistical analysis and the ANOVA table from Minitab, it was found that, at a significance level of 0.05, screw speed, barrel temperature, and all two-factor interactions were significant (p-value < 0.05). Although p-value of the head temperature was more than 0.05, p-value of the two-factor interaction of the head temperature was less than 0.05. Therefore, in the final conclusions, all three factors including screw speed, barrel temperature, and head temperature were significant to the edge crack defect.

Moreover, p-value of the curvature was also less than 0.05. This showed the significance of the curvature in the model. Therefore, the second order regression model was required to accurately optimize the level of the process parameters.

2. Response Surface Methodology (RSM)

A. Central Composite Design

Results from Minitab for Face-Centred Central Composite Design shows per below TableIII, at a significance level of 0.05, P-value of the 2-way interactions of barrel* head and speed*barrel are lower than 0.05 which can be concluded that all three main factors (i) speed, (ii) barrel temperature and (iii) head temperature influence to the quantity of edge crack defect. Therefore, the factors effect to the quantity of edge crack defect are screw speed, barrel temperature, head temperature, 2-ways interaction between barrel*head and 2-ways interaction between speed*barrel at a significance level of 0.05 is the final conclusion.

TABLE IIII
RESULT OF RSM

Response Surface Regression: quantity versus Block, speed, barrel, head

The analysis was done using coded units.

Estimated Regression Coefficients for quantity

Term	Coef	SE Coef	T	P
Constant	39.6250	1.5289	25.918	0.000
Block	1.3750	0.9383	1.465	0.150
speed	8.5500	0.9350	9.144	0.000
barrel	-9.4500	0.9350	-10.107	0.000
head	-0.8500	0.9350	-0.909	0.374
speed*speed	-16.0000	1.8765	-8.526	0.000
barrel*barrel	2.0000	1.8765	1.066	0.299
head*head	6.0000	1.8765	3.197	0.004
speed*barrel	6.1250	1.0454	5.859	0.000
speed*head	2.0000	1.0454	1.913	0.069
barrel*head	5.1250	1.0454	4.902	0.000

B. Response Optimizer

To optimize the level of each factors, response optimizer was performed by using minimize function which target is 0 points and the upper is 10 points which is the accepted quantity of this product. The optimal condition of these factors for all three responses were obtained as shown in Fig. 6.

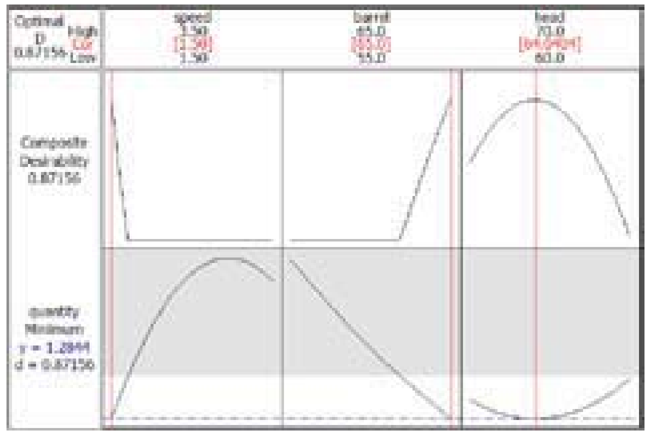

Fig. 6 Results of the optimal condition of three factors for all three responses

Per Fig 6, the optimal condition of these three factors to minimize the edge crack defect are screw speed to be 1.5 RPM, barrel temperature to be 65.0 degree Celcius and head temperature to be 64.04 degree Celcius, summary as shown per Table IV. The predicted values of the defect quantity is 1.2844 as shown in Fig. 6.

TABLE IV
OPTIMIZED FACTORS LEVEL

Factors	**Level**
Screw Speed	1.5 RPM
Barrel Temperature	65.00 Degree Celcius
Head Temperature	64.04 Degree Celcius

3. Confirmation run

A. Normality Check

The optimized level at 1.5 RPM of speed, 65 degree celcius barrel temperature and 64.04 degree celcius head temperature was tested with 20 replications. Normality test of the result was conducted and found that the data does not have normal distribution as p-value is less than 0.05 (95% confidential interval level) shown per Fig.7. Therefore, sign-test for non parametric was selected to check the median of the data.

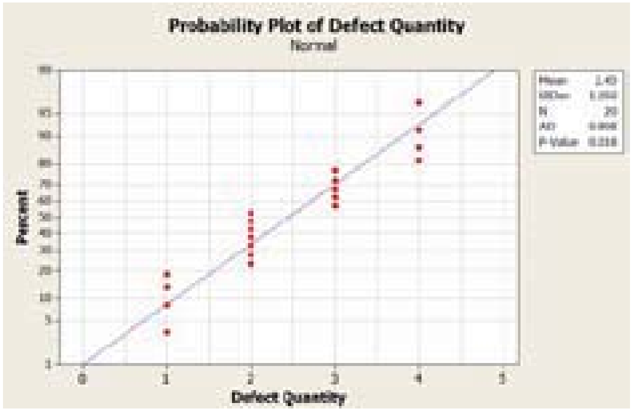

Fig. 7 Probability Plot for Confirmation Run.

B. Sign-test

Due to the defect quantity is quantity of point and the Y predicted from response optimizer is 1.2844 therefore we use quantity as 2 to test the median.

H_0 : Median of the defect quantity are equal.
H_1 : Median of the defect quantity are not equal.
At 95% confident interval (CI)

The result shows that it fails to reject H0 which can be concluded that the median of the defect quantity are equal.

TABLE V
RESULT OF THE SIGN TEST

Sign Test for Median: Defect Quantity

Sign test of median = 2.000 versus not = 2.000

	N	Below	Equal	Above	P	Median
Defect Quantity	20	4	7	9	0.2668	2.000

V. CONCLUSION

Face-centered composite design and Minitab were performed in this research and found that screw speed, barrel temperature and head temperature influence to edge crack defect quantity.

The optimal condition of the factors was summarized as follows:
1. Screw Speed was set at1.5 RPM.
2. Barrel Temperature was set at 65.00 Degree Celcius.
3. Head Temperature was set at 64.04 Degree Celcius.

Confirmation runs were performed using optimal condition to certify the results of the experimental analysis which showed predicted value of edge crack defect amount is 2 as per Fig 6. The sign test was performed to test the median of the 20 confirmation run results. It was found that the median was equal to 2 (p-value = 0.2668) at 95% confidence interval. Therefore, the results of the confirmation runs were not different from the result of the experimental analysis.

VI. SUGGESTION

Properties of compound material especially viscosity is interesting point for further investigate if it effects to reduce more edge crack defect as optimized level of this research still cannot reduce defect quantity to be zero which mean it would have other factors influence on. Lagging of information and limiting by the time made this research need to fix on the material to be the controlled factor.

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