The Application of Response Surface Methodology to Determine the Level Parameter Process in the Wasted of Powder Coal Solid Brick Manufacturing

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Abstract. *Nowadays, the solid brick demand is increasing due to of some economically conditions. Generally, the solid brick is manufactured by mixing the raw material cement and sand, and it causes.that the solid brick's price is relatively high. One alternative to subtitute the material is by using the wasted powder coal that has a cheaper cost. The purpose of this research is to find out the level of factors and their combinations that significantly influence the resistanced pressured strength of the wasted of powder coal solid brick. Response Surface Method has been used as the continuation of Taguchi Method due to that the two steps of the Taguchi Method could not be fulfilled. It is also found the combination of factors and their levels that minimized the variance of the value responses. The results had been implemented and it is proved that the resistanced pressured strength of the brick is increase and the responce variance is much smaller compared to the historical data*.

Key word : Powder coal solid brick, Response Surface Methodology,

1. INTRODUCTION

Nowadays, the need of the solid brick for structure and building is increasing due to the expansion of economics and the number of people growing in some area of business, especially in Indonesia. Generally, the basic material used in the structure and building is the solid brick made by mixing the raw material cement and sand. Using these materials create that the solid brick's price is relatively high. So it is a good idea to find the material alternative that makes the price becomes relatively low with the same quality or even better. One alternative is to use the wasted powder coal mixed with Padam calcium (as a fasten hydraulic). This mixing has the same idea used in making the regular solid brick that could be harden if the mixing placed in the water.

The wasted powder coal was chosen as the alternatine raw material based on the availabilty of this material. This material is easily found from the textile industry that using a boiler machine and the water electrically plant using coal as their energy resouces. The side outcome of this research is to reduce the number this material that unsafe to the human being.

The same research had been also done by the Balai Besar Keramik (the Ceramic Centre) with the purpose of the research is to discover the resistanced pressured strength that meet the Indonesian Quality Standard (SNI 03-0348-89). They performed the experiment using many levels of the controlled factors (by trial and error) to get the maximum resistanced pressured strength of the solid brick. Unfortunately, the resulted solid brick was categorized as B 25 level of quality standard or even worse. There are only some of the bricks that meet the B 40 Quality Standard (the higher level). This trial and error experiment should not be continued due to the high cost and the time that needed to perform the experiment.

This research uses the Response Surface Methodology as continuation of the Taguchi Method to determine the setting of factor levels in manufacturing of the powder coal solid brick with the maximum resistanced pressured strength result. The result can also be used to modify the Indonesian Quality Standard especially for the solid brick it self.

Then, the purposes of the research are :

1. To determine the factors that significantly effect the resistanced pressured strength of the powder coal solid brick.
2. To determine the optimal setting of those factors.

1.1 Problem Limittations

The followings are the problem limittations used in the research :

1. The interested quality characteristic is the pressured strength of the powder coal solid brick (kg/cm^2).
2. Water that used in the mixing process of lime and wasted powder coal is standardized at 6% up to 8%.
3. The factors that may effect to the quality characteristic are determined through the discussion with the experts.
4. The Interactions among the factors are considered for two factor interaction only.
5. Cost analysis is not performed.

1.2 Research Methodology

Research was performed at the Ceramic Centre with the object is the powder solid brick. The maximum resistanced pressured strength (in kg/cm^2) was the interested characteristic. Factors that influence to the quality charactristic are raw material composition, time for moisturing process, time for immersion process, formed brick pressure, silica content in the powder coal, and pollutant content in the lime.

The purpose of the research is to determine the factors and their interactions that significantly influence the quality characteristic. The data is collected and analyzed through the experiment. A mathematical model is performed to estimate the responsed surface and the factor levels are determined to optimize the quality characteristic. The last step of the research is to perform an experiment using those factors and their interactions. This experiment is called the confirmation experiment.

2. THE POWDER COAL SOLID BRICK

This brick is made by mixing the padam calcium (as a fasten subtance), water, and powder coal waste. Quality product at least should be agree with the Indonesian quality standard SNI 03-0348-89. This product is relatively new, so there is no standard that can be used. It is expected that this product can subtitude the current solid brick (concreted solid brick) that has relatively high price. This product should have the same quality standard as those the concreted solid brick. It is the reason that the SNI 03-0348-89 quality standard will be used.

2.1 Powder Coal Solid Brick Manufacturing Process

Generally, the powder coal solid brick is manufactured through the following steps :

1. The mixing of material
2. Formed brick process
3. Moisture process
4. Immersion process
5. Maintenance (it is also called the drying process)
6. The resistanced pressured strength testing

2.3 The powder Coal Solid Brick Quality Standard

According to the quality standard of SNI-03-0348-89, the solid brick quality can be categorized according to the minimum average resistanced pressured strength of the product, as shown in the following table:

Table 1. The Minimum Average ResistancedPressured Strength

Quality	the minimum average resistanced pressured strength (Kg/cm^2)
B 100	100
B 70	70
B 40	40
B 25	25

3. TAGUCHI METHOD

The purpose of the research is to manufacture the powder Coal Solid Brick with resistanced pressured strength as its quality standard. This quality standard is the measurable characteristic with higher-the- better class.

In the early stage of the research, the brainstorming with the experts (ceremical technological experts) was performed to determine the factors effecting the resistanced pressured strength of the brick. There are six factors that may affect the quality characteristic of the powder Coal Solid Brick. These factors are divided into two following groups:

1. Controlable factor. This group includes the material composition factor, that is the comparison between the powder coal with the lime, the moisture process time, the immersion process time, and the formed brick pressure.
2. Uncontrollable factor. This group is also called the noise factor. This factor is silica content in the powder coal and the pollutant content in the lime.

To determine the level of each factor, it was required to perform another discussion with the expert. From the the discussion, it can be concluded that all the factors are the continued parameters and the 2 level parameter for each factors are used. The following table shows the level of each factor that used in the experiment.

Table 2. The level treatment of the controllable factors

Controllable Factors	Level 1	Level 2
A. Material composition (%power coal weight : % lime weight)	5 : 1	6 : 1
B. Moisture process time (days)	3	7
C. Immersion process time (days)	3	7
D. Formed brick pressure(ton)	4	5

Table 3. The level treatment of the uncontrollable factors

Uncontrollable Factors	Level 1	Level 2
E. Silica content in the powder coal	<50%	>=50%
F. Pollutant content in the lime	<10%	>=10%

3.1 Orthogonal Array Determination

As explained above, the research used four controllable factors and two uncontrollable factors, then there are two steps in the orthogonal array selection, first is the selection of the orthogonal array applied to the controllable factors (it is called the inner array) and the second is the selection for the uncontrollable factors (it is called the outer array). By considering the number of factors and their interaction, and the number of level for each factors, it is decided that L_8 and L_4 are used for inner array and outer array, respectively.

3.2 Interaction Factor Determination Affecting the Quality Characteristic

Interaction factor determination is performed by discussion with the experts. From the discussion, it is found the interactions that may affect the quality characteritic:

1. Interaction between the controlled factor A and the controlled factor B
2. Interaction between the controlled factor A and the controlled factor C
3. Interaction between the controlled factor A and the controlled factor D

3.3 Factor Assignment and Their Interaction to the Orthogonal Array

The following table is used to assign the factors and their interactions in the column of orthogonal array.

Table 4. Orthogonal Array table for assignment process

OA	*Number of factors*	*Use Column nos.*
L4	1-2	1,2
	3	1-3
L8	1-3	1,2,4
	4	1,2,4,7
	5-7	1,2,4,7,(3,5,6)

(Source : Ross, 1996)

The uncontrolled factor E and F are assigned in the first and the second column of the orthogonal array L4, while the controlled factor A, B, C, and D are assigned in the first, second, forth, and seventh column on the orthogonal array L_8.

In the initial factor assignment to the orthogonal array L_8 (inner array), the third, fifth, and sixth column are not used yet until the expectation interaction (determined by the expert) are proven significantly.

The initial experiment shows that the controlled factor interactions are significant as expected by the expert, then to assign the factors and their interactions the following linear graph is used :

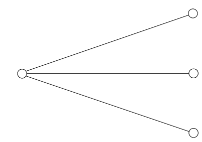

Figure 1. Linear Graph for L_8 Array (Inner Array)

Based on the linear graph, the assignment of the controlled factor in the orthogonal array is followed ;

Table 5. The assignment of controlled factor in the L_8 orthogonal array column

Column	*Assignment of Factor or Interaction*
1	A
2	B
3	A x B
4	C
5	A x C
6	A x D
7	D

Since there is no interaction between the uncontrolled factors, the linear graph is not required in assigning the uncontrolled factor to the array (as the outer array). The following is the assignment of the uncontrolled factor on the L_4 orthogonal array.

Table 6. The assignment of the uncontrolled factor to the column L_4 orthogonal array

Column	*Assignment of Factor or Interaction*
1	E
2	F
3	-

3.4 Analysis

After the data is collected through the experiment, the ANOVA calculation is performed to determine the mean responces by using the pooling strategy. This strategy will maximize the number of significant factors. The factors and the interactions that significant to the responces are A, B, C, D, E(the first noise), F(the second noise), AB, AC, AD, BE, CE, DE, ACE, ADE, AF, Bf, CF, DF, ACF, and ADF. It is assumed that the tree factor interaction (such as ADE) is not interested, then the tree factor interaction will not be considered in the analysis.

The ANOVA calculation to the variance is also performed. The calculation used the pooling up strategy, as well. The calculation shows that factor B and C effects the variance significantly.

3.5 Determination of Local Factors (mean) and Dispersion Factors (variance)

Determination of local factors and dispersion factors are performed after the ANOVA calculation for mean and variance.

Table 7. Adjustment Factor

		Location Factors (mean)	
		Exist	Not exist
Dispersion Factors (variance)	exist	B,C	-
	not exist	A,D	-

Table 7 shows that two step optimization procedure for Taguchi could not be satisfied. It is caused that effected factor for location (mean) and uneffected factor for dispersion (variance) are A and D. Yet, the effected factors for dispersion and uneffected factor for location could not be determined, then the Taguchi's optimization procedure for step1 is not fulfilled. There is also the interaction between the location factor and the dispersion, i.e., factors B and C. This condition also causes that the Taguchi's optimization for step 2 is not fulfilled.

Because the violation of the two steps optimization of Taguchi, then the determination of optimal parameter level using the Taguchi method can not be used. The research used the Response Surface Methodology to deterrmine the parameter level that could give the best resistanced pressured strength of the wasted of powder coal solid brick.

3.6 Response Surface Methodology (RSM)

3.6.1 Phase 1 : First-Order Model

The following is the general formula for the first order model used int the research :

$$\hat{y} = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5z_1 + b_6z_2 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{14}x_1x_4 + b_{25}x_2z_1 + b_{35}x_3z_1 + b_{45}x_4z_1 + b_{16}x_1z_2 + b_{26}x_2z_2 + b_{36}x_3z_2 + b_{46}x_4z_2$$

Where,

$\hat{y}$ = the responses

x_1 = factor A x_4 = factor D

x_2 = factor B z_1 = factor E

x_3 = factor C z_2 = factor F

Data applied to derive the regression model is found from the former data used in the Taguchi experiment, where every treatment value is determined by the average value from three replication values. The first order model is also derived by adding a middle point in the experiment with four replications. Using the least square method, the first order model is foumd as following :

$$\hat{y} = 37.529 - 0.116x_1 - 1.978x_2 - 5.268x_3 + 1.095x_4 - 0.453z_1 + 2.795z_2 - 0.920x_1x_2 - 0.239x_1x_3 + 0.441x_1x_4 + 0.839x_2z_1 + 1.811x_3z_1 + 0.261x_4z_1 + 1.516x_1z_2 + 0.932x_2z_2 - 0.970x_3z_2 + 0.622x_4z_2$$

The determination coefficient for this equation is 0.234. The test of Lack Of Fit and significant of this equation is shown in the following ANOVA table :

Table 8. ANOVA for Regression and Lack of Fit First Order Model

Sources of variability	Sum of Square	DOF	Mean Square	F	F table (α=0.05)	Conclusion
Regression	1617.066	16	101.067	1.595	2.253	Ho is accepted
Curvature	4164.55	1	4164.549	802.418	10.100	Ho is not accepted
Error	1140.261	18	63.348			
Lack of Fit	1124.691	15	74.979	14.447	8.700	Ho is not accepted
Pure error	15.570	3	5.190			
Total	6921.876	35				

The table shows that there is no even one regressor variable that has significant contribution to the model, and There is also a significant lack of fit. Then the first order model can not be used as a representative of the true model. Table also shows that the curvature exists in the model. The steepest ascent method can not also be used in the research. It can be concluded that the regression model is not linear and the second step of RSM can be started.

3.6.2 Phase 2 : Second Order Model

The general formula for the second order model is following :

$$\hat{y} = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5z_1 + b_6z_2 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2 + b_{44}x_4^2 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{14}x_1x_4 + b_{25}x_2z_1 + b_{35}x_3z_1 + b_{45}x_4z_1 + b_{16}x_1z_2 + b_{26}x_2z_2 + b_{36}x_3z_2 + b_{46}x_4z_2$$

The Central Composite Design (CCD) is used for the second order model. This design consists of two levels of factorial combined with the 2k axial point or the star point. The experiment is performed using the following data :

Table 9. The testing points at the Central Composite Design

Factor	Coordinate (in the coded unit)					1 *Design Unit*	Unit
	-2	-1	0	1	2		
X1. Material composition	6.5	6	5.5	5	4.5	0.5	%
X2. Moisture process time	9	7	5	3	1	2	Days
X3. Immersion process time	9	7	5	3	1	2	Days
X4. Formed brick pressure	5.5	5	4.5	4	4.5	0.5	Ton

The following is the second order regression model :

$$\hat{y} = 65.767 - 0.444x_1 - 1.808x_2 - 4.998x_3 + 1.059x_4 - 0.453z_1 + 2.795z_2 - 5.302x_1^2 - 8.977x_2^2 - 7.840x_3^2 - 9.090x_4^2 - 0.920x_1x_2 - 0.239x_1x_3 + 0.441x_1x_4 + 0.839x_2z_1 + 1.811x_3z_1 + 0.261x_4z_1 + 1.516x_1z_2 + 0.932x_2z_2 - 0.970x_3z_2 + 0.622x_4z_2$$

Table 10. ANOVA for the regression and Lack of Fit Second Order Model

Sources of Variability	Sum of Square	DOF	Mean Square	F	F table (α=0.05)	Conclusion
Regression	7126.628	20	356.331	6.622	2.013	Ho is not accepted
Linear	1438.965	6	239.828	4.457	2.345	Ho is not accepted
Square	5687.663	14	406.262	7.550	2.115	Ho is not accepted
Error	1345.269	25	53.811			
Lack of Fit	1269.116	20	63.456	4.166	4.560	Ho is accepted
Pure error	76.153	5	15.231			
Total	8471.898	45				

The second order model can explain 84.1% of the response surface function. The ANOVA table shows that at least one of regressor variables, linearly and quadratical result contributes significantly to the model. Significantly, there is no lack of fit to the model, as well. The second order model is representative to the surface response model.

3.7 The RSM Application in Solving the Case of Noise Factor

The RSM method is used to solve the noise factor problem. The second order model, as found before, will be devided into two groups. One group is without noise and will be maximized and the other is with noise and will be minimized.

The following is the maximum response model :

$$E_z[y(x,z)] = 65.767 - 0.444x_1 - 1.808x_2 - 4.998x_3 + 1.059x_4 - 5.302x_1^2 - 8.977x_2^2 - 7.840x_3^2 - 9.090x_4^2 - 0.920x_1x_2 - 0.239x_1x_3 + 0.441x_1x_4$$

and the minimum response model is :

$$\mathrm{Var}_z\left[y(x,z)\right] = 61.828 + 8.474X_1 + 4.450X_2 - 7.063X_3 + 3.241X_4 + 2.298X_1^2 + 1.573X_2^2 + 4.221X_3^2 + 0.455X_4^2 + 2.826X_1X_2 - 2.941X_1X_3 + 1.886X_1X_4 + 1.231X_2X_3 + 1.597X_2X_4 - 0.261X_3X_4$$

After derivation of both the maximum response model (for the response value)and the minimum response model (for variability), the picture of those models can be made (as shown on figure 2). Those figures are overlaid as shown on figure 3. This process is also called the Dual Response Surface. The overlay for these pictures is performed to find the optimal value that maximize the response value and minimize the the variability.

Since the four factors, X_1, X_2, X_3, and X_4, has a positive effect on the average response value, then to obtain the optimal value that maximize the response value and minimize the variability, the two controllable factors from four controllable factors will set on the combination -1, 1, and 0, consecutively. Then there will be 54 combinations of setting level from the possible hold factors. From these combinations there is only one feasible combination that gives E (the response) > 62.3 kg/cm^2 and POE (the variabiliy) < 7.5. This combination gives the setting level $X_3 = 0$, $X_4 = 0$, $Z_1 = 0$, and $Z_2 = 0$.

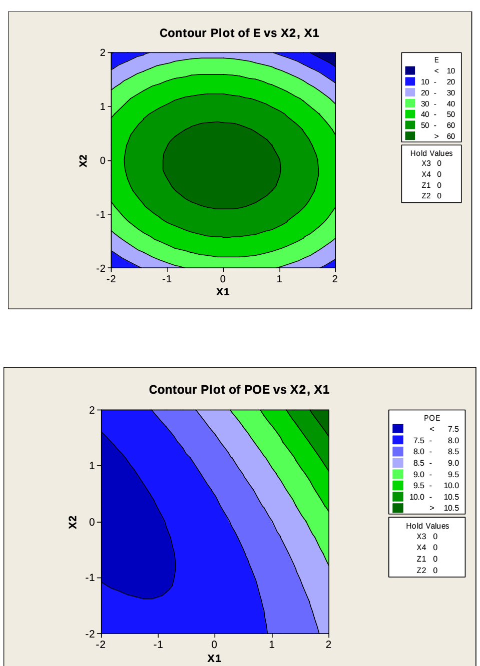

Figure 2. Contour Plot E and POE Response with *Setting Level* $X_3 = 0$, $X_4 = 0$, $Z_1 = 0$, and $Z_2 = 0$

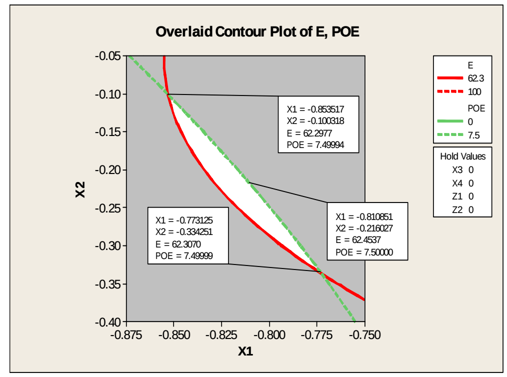

Figure 3. *Overlaid Contour Plot* i E and POE Response with *Setting Level* $X_3 = 0$, $X_4 = 0$, $Z_1 = 0$, $Z_2 = 0$

Factor level for X_1 and X_2 that give the optimal result can be easily found from the setting level $X_3 = 0$, $X_4 = 0$, $Z_1 = 0$, and $Z_2 = 0$. It is found that both X_1 and X_2 are set on -0.810851 and -0.216027, respectively.

By adjusting the factor to those values, theoretically, it is hoped that the resistanced pressured strength is at least 62.5437 kg/cm^2 with the minimum response surface variance is 7.5.

After some considerations, each factor level should be adjusted so these factor levels can be used in the manufacturing. The followings are the factor level for each factor generated from the Response Surface Method :

1. The factor level of X_1, material composition (% powder coal weight : % lime weight), is set on 5.9% : 1%
2. The factor level of X_2, the moisture process time, is set on 5.5 days.
3. The factor level of X_3, the immersion process time, is set on 5 days
4. The factor level of X_4, formed brick pressure, is set on 4.5 ton

3.8 Confirmation experiment

This experiment is performed by manufacturing a number of the wasted of powder coal solid brick using the combination of the controllable factor levels generated by this research. The analysis is done by performing the following testing :

- The mean testing between the confirmation experiment and the research itself.
- The variance testing between the confirmation experiment and the research itself.
- The mean testing between the confirmation experiment and the historical data.
- The variance testing between the confirmation experiment and the historical data.

Some conclusions are derived based on the testing mentioned above :

- The mean response values (the resistanced pressured strength) of the confirmation experiment is not different significantly with the mean response of the research.
- The variance response values of the confirmation experiment is not different significantly with the variance response of the research using the calculation formula.
- The mean response values of the confirmation experiment is better than the mean response of historical data.
- The variance response values of the confirmation experiment is better than the variance of the historical data.

4. Conclusion

The followings are the conclusion for the research :

- The controllable factors that significantly affecting the resistanced pressured strength of the wasted of powder coal solid brick are :
  a. The material composition (%powder coal weight : % lime weight)
  b. The moisture process time (days)
  c. The immersion process time (days)
  d. The formed brick pressure(ton)
- The controllable factors that significantly effecting the variance are :
  a. The moisture process time (days)
  b. The immersion process time (days)
- The uncontrollable factor that significantly affecting the resistanced pressured strength of the wasted of powder coal solid brick are :
  a. The pollutant content in the lime
  b. The silica content in the powder coal
- The combination level factors that give the maximum resistanced pressured strength and the minimum variance are following :
  a. X_1 (the material composition) is 5.9% : 1%
  b. X_2 (the moisture process time) is 5.5 days
  c. X_3 (the immersion process time) is 5 days
  d. X_4 (The formed brick pressure) is 4.5 ton

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