ISSN 1746-7659, England, UK
Journal of Information and Computing Science
Vol. 3, No. 4, 2008, *pp*. 313-320

Optimal setting of level production factors in the ceramic wall brick manufacturing to maximize the resistanced pressured strength

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(*Received August 12, 2008, accepted October 12, 2008*)

Abstract. One component of building that usually needed to make the building good looking is the use of the ceramic wall brick. There are many types of this product found in the market and some of them do not conform to the quality standard, especially for the products produced by the local manufacturer. It causes that the product produced locally does not have any power to compete with the same product produced from other countries. The quality standard that usually interested is the resistanced pressured strength (kg/cm^2). The research uses the Response Surface Method (RSM) to determine factors and their combination used to fulfill the quality standard of the product or even better. Some factors that affect the quality standard are the particle size, formed brick pressure, and burning temperature. It can be concluded from the research that the level for these factors are 200 mesh, 200 kg/cm^2, and 1194 ^{o}C, respectively. The result has been implemented and it is found that the mean and variance response of quality standard for this confirmation experiment is not different significantly with the research, but much better than the products manufactured locally.

Keywords: The ceramical wall brick, Taguchi method, Response Surface Methodology

1. Introduction

Nowadays, the ceramic wall brick is used to make a building good looking. There are many types of these products found in the market. Unfortunately most of them do not have a good quality, especially the product produced locally, so these products do not have power to compete with those produced overseas. The quality focused in this research is the resistanced pressured strength. This quality will effect to the product quality especially related to the occurrence of crack that frequently exist.

Factors that affect to the quality are divided by the following two groups (Ross, 1996):

- Controllable factors. This group includes the particle size, the formed brick pressure, the burning temperature, and the material composition. The material composition is determined by applying the feldspar taken from Banjanegara city, the clay is taken from Sukabumi city, and the Quartz is taken from Cicalengka city. Proportion of this material is 0.45 for feldspar, 0.40 for clay, and 0.15 for Quartz, respectively.
- Uncontrollable factors. This group is the pollutant content (K_2O and Na_2O) in the feldspar material. This factor has two levels, the first level is less than 6%, and the second level is greater or equal to 6%, respectively.

2. The Purpose of the Research

The purpose of this research is to determine the optimal level of the controllable factors and their interaction that significantly affect the quality of the ceramic wall brick. Using these levels will also give the maximum resistance pressured strength of the ceramic wall brick. It is hoped that this resistance pressured strength resulted from the research will fulfill the Indonesian quality standard (SNI 03-0054-1996). For this purpose, the Response Surface Methodology (RSM) was used in determining the optimal level of the

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controllable factors. RSM is the mathematically and statistically engineering application used to analyze the problems where some independent variables influence the dependent variable. Its objective is to optimize the response (Montgomery, 1976). Based on the information above, it can be concluded that the purpose of the research are:

- To determine the factors that significantly affect the resistance pressured strength of the ceramic wall brick.
- To determine the combination level of the factors that gives the maximum resistance pressured strength of the ceramic wall brick.

2.1. Problem Limitations

The research is limited by the following circumstances:

- The product interested in the research is the ceramic wall brick with the dimension 11 cm x 11 cm.
- The brick material composition is determined in advance
- The interaction interested in the research is two interaction factors only.
- The Pollutant content is determined in advance.

2.2. Research Methodology

Research was performed at the Centre for Ceramics with wall brick as the object. Interested quality product is the resistanced pressured strength (kg/cm^2) and the influenced factors for the research are particle size, the formed brick pressure, the burning temperature, and the material composition. Experiment was performed to collect data. Based on these data, the factors that effect to the resistance pressured strength were determined. The next step is to formulate a mathematical model used to estimate the response surface. This responsed surface is used to determine the level of each factor that maximizes the resistance pressured strength. The confirmation experiment was performed using the factors with their optimal levels.

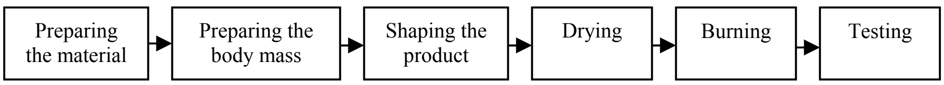
2.3. The Wall Brick

The wall brick is a product that used in the wall surface with smaller thickness compare to the surface area. Based on the Indonesian Quality Standard (SNI 03-0054-1996), this product is one of the building components used to cover the wall surfaces with square in shape, made by the mixing of clay and other ceramic substances, and burned with high temperature to get a specific characteristic.

The followings are the benefits in application of this product:

- It gives the sense of neatness and healthiness
- It could not absorb the colour water that spill to the wall
- The maintenance is relatively simple

The followings are the manufacturing process of the product:



The following table also shows the quality standard of the product (according to Indonesian Quality Standard SNI 0023-73)

Table 1. The Minimum Rresistance Pressured Strength

Wall Brick Thickness	Resistanced Pressured Strength
< 7.5 mm	12
≥7.5 mm	15

3. Design Experiment

The levels of every group factor are shown on the following table 2 and 3. These levels were determined based on the discussion with the experts.

Table 2. The Levels of Controllable Factors

Controllable Factors	Level 1	Level 2	Level 3
A. Particle Sizes (mesh)	100	140	200
B. Formed Brick Pressure (kg/cm^2)	150	150	200
C. Burning Temperature (^oC)	1150	1200	1250

Table 3. The Levels of Uncontrollable Factors

Uncontrollable Factors	Level 1	Level 2
Pollutant (K_2O, Na_2O)	$\leq 6\%$	$> 6\%$

The screening design experiment (phase 0) was performed in the initial of The RSM. The purpose of this phase is to determine whether the factors will significantly affect to the interested response, in this case is the resistance pressured strength. Due to the existence of the uncontrollable factor (noise), then the Taguchi designed experiment was used. The choice of the orthogonal array (OA) is based on the number of factors and their interactions in the experiment. The research contains three controllable factors (A, B, and C); each has three levels, and one uncontrollable factor (X) with two levels. Based on the discussion with the expert, it can be concluded that there are many factor interactions exist in the manufacturing of the product. Particle size interacts with formed brick pressure (AxB), particle size interacts with burning temperature (AxC), and formed brick pressure interacts with burning temperature (BxC). Determination of the orthogonal array is performed based on the number of degree of freedom (DoF) by using the following equation:

$$
\begin{aligned}
DoF &= n + 2m + a\,(b-1)\,(c-1) + 1 \\
&= 0 + 2(3) + 3\,(3-1)\,(3-1) + 1 \\
&= 19
\end{aligned}
$$

where m :

n: the number of two-level factors

m: the number of tree-level factors

a: interaction between two factors

b, c: the value might be two or tree depend on interaction factor level

Based on this number, the research used the L_{27} orthogonal array. The position of every factor and their interactions is performed using the linear graph. The following figure is the linear graph of the research.

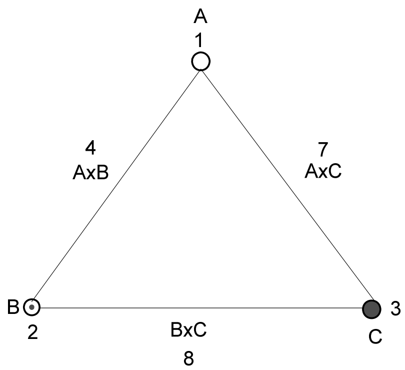


Figure 1. The linear Graph of the research

The data experiment was input to the ANOVA using the pooling up strategy. It is found that factor A, B, C, interaction A and C, interaction B and C, factor X (noise), and interaction C and X significantly affect the mean response of the experiment. It is also found that factor A, B, and C significantly affect the variance or dispersion.

The following adjustment factor table determines the position of the factors that significantly affect the location and dispersion.

Table 4 Adjustment Factor

		Location factors (mean responce)	
		exist	Not exist
Dispersion factors (variance)	exist	A,B,C	-
	Not exist		-

Based on the position of the factors, it can be concluded that there is the violation to the first step of the two step Taguchi optimization, then the Taguchi experiment could not be used to determine the optimal level of the factors. This problem can be solved by using the Response Surface Methodology (RSM).

3.1. Response Surface Methodology

The general equation for the first order model for the research is:

$$\hat{y} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_{12} X_1 X_2 + \beta_{23} X_2 X_3 + \beta_{14} X_1 X_4 + \beta_{24} X_2 X_4 + \beta_{34} X_3 X_4$$

Where:

$\hat{y}$ = responses

X_1 = factor A X_3 = factor C

X_2 = factor B X_4 = factor X

The transformation is performed to make the calculation less complicated. This transformation uses the following formula:

$$X_{i1} = \frac{\xi_{i1} - [\max(\xi_{i1}) + \min(\xi_{i1})]/2}{[\max(\xi_{i1}) - \min(\xi_{i1})]/2} = \frac{\xi_{i1} - [200 + 100)]/2}{[200 - 100)]/2} = \frac{\xi_{i1} - 150}{50}$$

$$X_{i2} = \frac{\xi_{i2} - [\max(\xi_{i2}) + \min(\xi_{i2})]/2}{[\max(\xi_{i2}) - \min(\xi_{i2})]/2} = \frac{\xi_{i2} - [150 + 200)]/2}{[200 - 150)]/2} = \frac{\xi_{i2} - 175}{25}$$

$$X_{i3} = \frac{\xi_{i3} - [\max(\xi_{i3}) + \min(\xi_{i3})]/2}{[\max(\xi_{i3}) - \min(\xi_{i3})]/2} = \frac{\xi_{i3} - [1250 + 1150)]/2}{[1250 - 1150)]/2} = \frac{\xi_{i3} - 1200}{50}$$

The result of this transformation is the code shown in the following table 5.

Table 5. Table of factor level transformation to a code

No	Factor A (ξ_1)	Factor B (ξ_2)	Faktor C(ξ_3)	(X_1)	(X_2)	(X_3)
1	100 mesh	150 kg/ cm^2	1150 ^{o}C	-1	-1	-1
2	140 mesh	175 kg/ cm^2	1200 ^{o}C	-0.2	0	0
3	200 mesh	200 kg/ cm^2	1250 ^{o}C	1	1	1

The regression equation for the first order model is:

$$\hat{Y}_1 = 13.93 + 0.941X_1 + 1.189X_2 – 2.032X_3 – 2.929\ X_4 + 0.008\ X_1X_2 + 0.088\ X_2X_3 – 0.13\ X_2X_4 + 0.109\ X_3X_4 + 0.021\ X_3X_4.$$

The following ANOVA is used to determine whether the regression coeffisient is significant to the equation:

Table 6. ANOVA table for the regression

Source	Df	SS	MS	Ftest	Ftable	Conclusion
Regression	9	2100.04	233.34	13.26	2.53	Not significant
Error	152	2674.90	17.60			
Lack of fit	44	2649.08	60.21	251.83	1.75	Not significant
Pure Error	108	25.82	0.24			
Total	161	4774.94				

ANOVA table shows that the first order model is not fit to the data. The coefficient determination (SS_R/SS_T) also shows that this first order model could not explain the true response. The next approximation is to use the second order model to the data with the following general formula:

$$\hat{Y} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_{11} X_1^2 + \beta_{22} X_2^2 + \beta_{33} X_3^2 + \beta_{12} X_1 X_2 + \beta_{23} X_2 X_3 + \beta_{34} X_3 X_4$$

By using the same data, the second order regression model is as follow:

$$\hat{Y} = 19.61 + 0.959X_1 + 1.189X_2 - 2.032\,X_3 - 2.938X_4 - 0.294X_1^2 + 0.043X_2^2 - 8.260\,X_3^2 + 0.008\,X_1X_2 + 0.088\,X_2X_3 - 0.021\,X_3X_4.$$

The following is the ANOVA table for this second order model:

Table 7. The ANOVA table for second order model

Source	df	SS	MS	Ftest	Ftable	Conclusion
Regression	10	4553.446	455.34	310.4292	1.8939	Significant
Error	151	221.490	1.4668			
Total	161	4774.936605				

The table shows that the second order model is fit to the data. The coefficient determination for this model is 0.9536; it means this model has capability to explain 95.36% of the response surface.

The next step of this method is to split the second order equation into two partitions. One partition does not contain the noise factor and will be maximized, and the other contains the noise factor and will be minimize. The model or equation (response surface for the process mean) that will be maximized is:

$$E_z[y(X,z_1)] = 19.61 + 0.959X_1 + 1.189X_2 - 2.032\,X_3 - 0.294\,X_1^2 + 0.043\,X_2^2 - 8.260\,X_3^2 + 0.008\,X_1X_2 + 0.088\,X_2X_3$$

The model or equation ((response surface for the process variance) that will be minimized is:

$$Varz[y(X,z_1)] = \sigma_z^2(-2.938 - 0.021X_3)^2 + \sigma^2;\ \text{where } \sigma_z^2 = 1,\ \sigma^2 = MS_{error} = 1.467$$

$$= 8.633 + 0.1234X_3 + 0.00044X_3^2 + 1.467$$

$$= 10.1 + 0.1234\,X_3 + 0.00044\,X_3^2$$

Both models will be figured out by using the contour plot called the dual response surface, and those contour plots will be overlaid. From six combinations of contour plot for E and POE, there are only two contour plots E with the maximum of the resistanced pressured strength, and two contour plots for POE. Each combination will be overlaid to obtain the maximum response (resistanced pressured strength) and the minimum variance. The following is the combination:

a. Figure 2 shows the contour plot where the factor X_1 at level 1 and factor X_4 at level 0. The contour plot of POE is shown in figure 3, and the overlaid for these two figures is shown in figure 4.

b. Figure 5 shows the contour plot where the factor X_2 at level 1 and factor X_4 at level 0. The contour plot of POE is shown in figure 6, and the overlaid for these two figures is shown in figure 7.

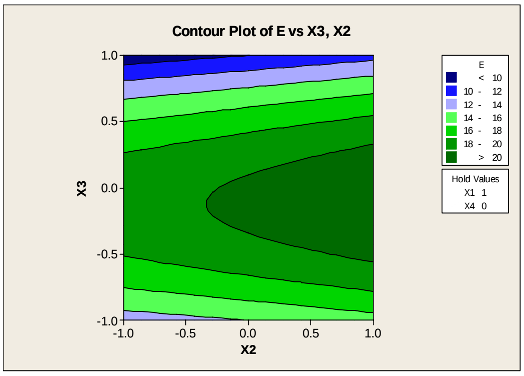


Figure 2. The Contour Plot E of resistanced pressured strength where X_1= 1and X_4= 0

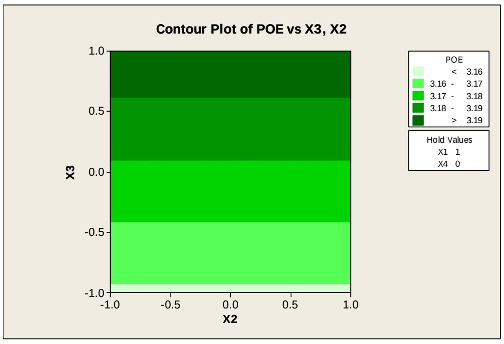


Figure3. The Countur Plot POE of resistanced pressured strength where X_1= 1and X_4= 0

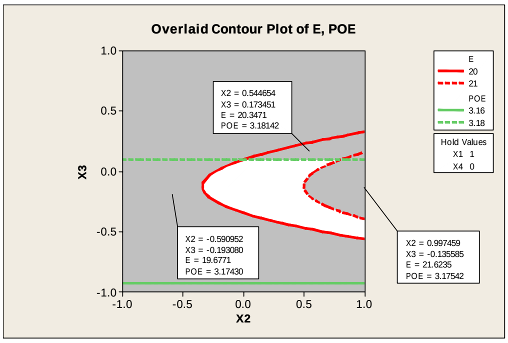


Figure 4. The Overlaid Contour Plot with X_1 = 1 and X_4 = 0.

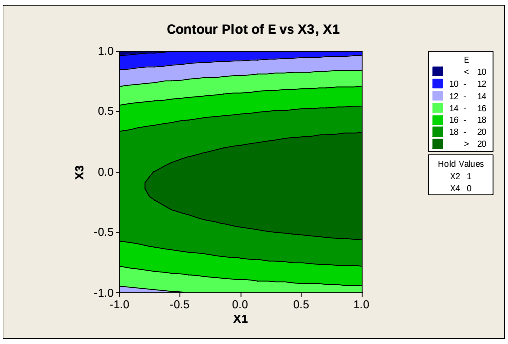


Figure 5. The Countur Plot E of resistanced pressured strength where X_2= 1and X_4= 0

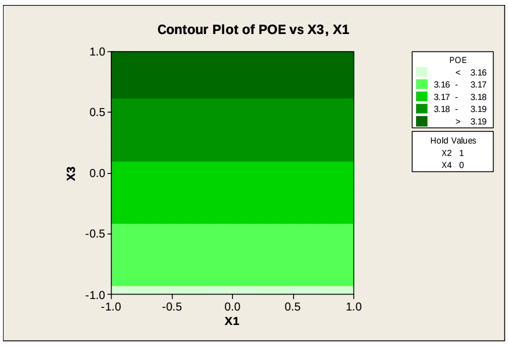


Figure 6. The Countur Plot POE of resistanced pressured strength where X_2= 1and X_4= 0

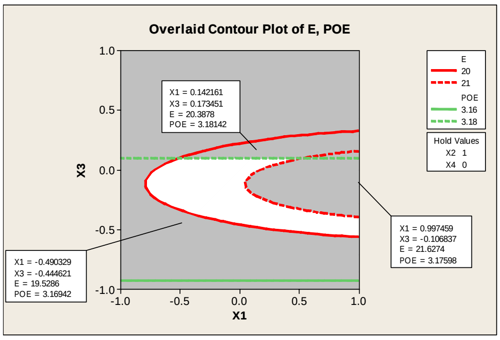


Figure 7. The Overlaid Contour Plot with $X_2 = 1$ and $X_4 = 0$.

By using the software MINITAB, the maximum of resistanced pressured strength (21.623 kg/cm^2) is found by setting the factor X_1 at level 1, X_2 at level 1, and X_3 at level -0.1155. It is similar with X_1 equal to 200 mesh, X_2 equal to 200 kg/cm^2, and X_3 equal to 1194^{o}C, respectively.

4. Confirmation Experiment

The purpose of this experiment is to find out whether the combination level resulted from the research will give the better strength. From the testing with confirmation experiment, it can be concluded that:

a. The mean response of confirmation experiment is similar with the mean response of the research.

b. The mean response of confirmation experiment is better significantly with the mean response of the products produced locally.

c. The mean response of confirmation experiment is similar with the mean response of the products produced from other countries.

5. Conclusion

Based on the experiment, there are some conclusions that can be derived:

- There are some factors that can significantly affect the resistance pressured strength of the wall brick. Generally, the factors can be divided by two groups. One group is called the controllable factor, such as, the particle size, the formed brick pressure, and the burning temperature. Another group is called the uncontrollable factor, i.e., the pollutant (K2O, Na2O). Some interactions among the factor also significantly affect the resistance pressured strength of the wall brick.
- The combination level of the factor that can maximize the resistance pressured strength is:
    1. The particle size is 200 mesh
    2. The formed brick pressure is 200 kg/cm^2
    3. The burning temperature is 1194^{o}C

6. References

[1] Bagchi, P Tapan. *Taguchi Methods Explained, Practical Steps to Robust Design*. New Delhi: Prentice Hall International. 1993.

[2] Blank, Leland. *Statistical Procedure for Engineering, Management, and Science*, McGraw-Hill, 1982.

[3] Cochran, G William and M Gertrude. *Cox. Experimental Designs*, 2nd ed. New York: John Wiley & Sons Inc. 1959.

[4] Hicks, R Charles. *Fundamental Concepts in the Design of Experiments*, Fourth Ed. Holt-Saunders International Editions, 1993.

[5] Mitra, Amitava. *Fundamental of Quality Control and Improvement*, 2nd ed. New Jersey: Prentice Hall, 1998.

[6] Montgomery, Douglas C. and Myers, Raymond H. *Response Surface Methodology*, 2nd ed., New York: John Wiley & Sons Inc. 2002.

[7] Ross, J Phillip. *Taguchi Techniques for Quality Engineering*. 2nd ed., New York: McGraw-Hill, 1996.