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MULTIRESPONSE OPTIMIZATION ON THE PROCESS OF ROOF TILES MANUFACTURE USING THE TAGUCHI AND PCR-TOPSIS METHOD

Cucuk Nur Rosyidi, Ariawan Budiaji, Eko Pujiyanto

IE Department Universitas Sebelas Maret, Building I Faculty of Engineering, Jalan Ir. Sutami 36 A Surakarta, Indonesia

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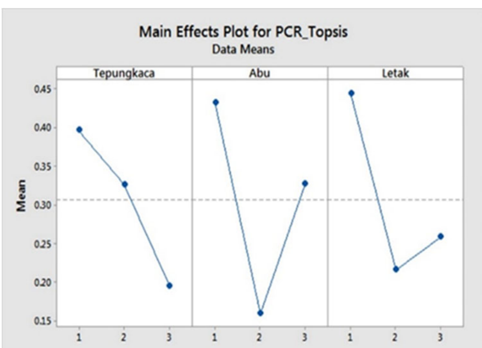
*Corresponding author:
cucuknur@staff.uns.ac.id

Graphical abstract



Abstract

Most people on Java Island in Indonesia use roof tiles as roofs for their buildings. The advantages of tile include the availability of various models, cheaper price, light weight, easy installation process, absorb heat, low noise when exposed to rain, and durable. The tiles produced by small and medium industries have not met the quality requirements. This study was conducted to determine the optimum factor and level in the roof tiles production by adding glass powder and wood ash into clay and the variation of roof tiles placement on kiln. Glass powder and wood ash contain of silicon dioxide of about 85%. It is an important substance to increase the strength of the tile. Meanwhile the responses measured in the study were compressive strength, visual testing, water absorption, and water permeability. Taguchi method is used to improve the product quality and production processes with high efficiency in both cost and the number of treatments. PCR-TOPSIS Method was used to determine the optimal setting of the process parameters. From the optimization results, the optimum combination of level factors is $A_1B_1C_1$ (4% of glass powder, 4% of ash, and first level of the kiln placement).

Keywords: Roof tiles, Taguchi, multiresponse, PCR-TOPSIS, kiln

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1.0 INTRODUCTION

Most people on Java Island in Indonesia use roof tiles as building roofs. According to Central Bureau of Statistics data (known as BPS or Badan Pusat Statistik in Indonesia), more than 90% of houses in Java Island use roof tiles. For instance, in Boyolali, Wonogiri, and Klaten Regency of Central Java Province, there are respectively 98.39%, 95.41%, and 98.10% of houses using roof tiles. The advantages of roof tiles include the availability of various models, affordable price, light weight, easy to install, absorb heat, not noisy when they are exposed to rain, and have a high durability.

Some studies have been carried out in the effort to improve the quality of roof tiles. Pratiwi *et al.* (2014) used glass waste as the additional materials in the process of roof clay production which results in an enhancement of roof tiles in terms of compressive strength and reduction of water permeability. Glass is a solid material that according to Ramadani (2018) consists of 84.20% silicon dioxide compound (SiO_2) and 12.37% CaO. Another study by De Silva and Surangi (2017) added rice husk ash in the process of roof tiles production. The study resulted in the enhancement of roof tiles quality in terms of compressive strength, and reduction of room temperature. Wood ash consists of SiO_2(31.8%), Al_2O_3(28%), Fe_2O_3(2.34 %), CaO(10.53%), MgO(9.32%), Na_2O(6.5%), and K_2O(10.38%) (Grau *et al.* 2015). SiO_2 which is also known as silica or quartz has two forms which are α-quartz and β-quartz. When a-quartz is burned above the temperature of 573 °C, it will change into β-quartz that is stable in the temperature of 870 °C, and if it is burned above the temperature of 870 °C, it will change into tridymite. Tridymite has 7 Mohs hardness scale (Rasma, *et al*. 2011). Hence, as the results of previous researches, glass powder and wood ash have a high potential to increase some quality characteristics of the clay roof tiles.

In this study, the roof tiles are made from clay and two additional materials, namely glass powder and wood ash. The percentage of those mixtures added to clay along with the variation of roof tile locations on kiln are used as the factors in this study. Taguchi method is used to improve the quality of product that makes the product/process robust to noise factor.

Traditional Taguchi method can only be used to solve single response problems. In practice, a product may have more than one quality characteristic (multiresponse) that must be optimized simultaneously. For that need, PCR-TOPSIS has been widely used as an analysis method to determine the optimum setting of process parameters in Taguchi multiresponse problems.

The aim of this study is to determine the optimum factor and level in the roof tiles production by adding glass powder and wood ash into clay and the variation of roof tiles placement on kiln with the responses of compressive strength, visual display, absorption and water permeability.

Rasma, *et al*. (2011), conducted a research and concluding that about 81.25% of the roof tiles have not conformed with the quality standard as set in the SNI, the conformance of ceramic roof tiles product from several small industries in the area of Java, Aceh, and Nusa Tenggara Barat to Indonesian National Standard (known as SNI) was tested. Some important parameters used in the research include display quality, size accuracy, water absorption and bending load. Some studies in the field of process optimization of roof tile production and related products have been conducted. For example, Karolina *et al*. (2013) have conducted a research to determine the effect of adding volcanic ash of Sinabung mountain in North Sumatera as fine aggregate material in brick production toward the water absorption, compressive strength, visual display, and concrete brick dimension. The flat surface of concrete brick is caused by the particle size of the volcanic ash that is similar to cement so it can fill the sand aggregate cavity and results better concrete brick in terms of solidity and flatter surface.

Pratiwi *et al*. (2014) conducted a research to maximize bending load and minimize water permeability on roof tiles by adding glass powder into clay. From the result of regression analysis, it was found that the optimal composition of the glass powder is 9.817% with the resulted bending load of 69.469 kg. In research results showing that roof tiles with 10% rice husk ash resulted in 45.97% higher bending load than conventional roof tiles, De Silva and Surangi (2017) aimed to find out the effect of adding rice husk ash toward compressive strength, density, water absorption, water permeability, temperature and water flow characteristic on the clay roof tiles.

This study used two additional materials, namely glass powder and wood ash, which is added simultaneously in the roof tiles production from clay to increase the response parameters of the roof tile, meanwhile, in previous studies only one additional material was used to increase the response. Karolina *et al*. (2013), Rai, S. *et al*. (2013), De Silva and Surangi (2017) only added material in the form of ash in their research. Pratiwi *et al*. (2014), Bayarzul and Temuujin (2017), Kazmi, S. M. S. *et al* (2017), and Mozo, W. *et al*. (2019) only added material in the form of glass powder in their research. In addition, this study uses the position of the tile on the kiln as a factor in the study, which has not been used as a factor in previous studies. Table 1 shows the position of this research relatives to the other related researches.

Table 1 Research factors and levels

RESEARCHERS	FACTORS													RESPONSES																	DATA ANALYSIS					
	1	2	3	4	5	6	7	8	9	10	11	12	13	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	1	2	3	4	5	6
	Clay	Glass powder	Wood ash	Mountain ash	Sand	Cement	Mud	Temperature variation	placement of roof tile	Stone ash	Milling variable	Palm fiber	Cashew shell liquid	Visual	Size	Water absorption	Water permeability	Smooth flow	Compressive strength	Tensile strength	Density	Temperature	Temperature shock	PH	Violence	Shrinkage	Resistance	Plascity	Mineral composition	Cost	Optimization	Factorial	Regression analysis	ANOVA	Taguchi	PCR-TOPSIS
Hijayanti (2007)								√						√			√		√		√					√					√					
Ducman, V. *et al*. (2010)								√											√								√				√					
Gömze, L.A. (2010)											√																		√			√				
Rasma, A. *et al*. (2011)	√													√	√	√	√		√				√								√					
Tiamiyu and Ibitoye (2012)	√											√	√			√			√	√										√	√					

Table 1 (Continued)

RESEARCHERS	FACTORS													RESPONSES																	DATA ANALYSIS					
Rai, Suchita *et al.* (2013)			√				√	√																√										√	√	
Pratiwi, C. *et al.* (2014)	√	√															√		√														√			
Karolina, R. *et al.* (2015)				√	√	√								√	√	√			√												√					
Sultana, S. *et al.* (2015)	√	√								√						√			√												√					
De Silva and Surangi, (2017)	√		√												√	√	√	√	√	√	√	√									√					
Bayarzul and Temuujin (2017)	√	√																			√				√						√					
Kazmi, S. *et al.* (2017)	√	√																								√					√					
Mozo, W. *et al.* (2019)	√	√					√								√				√									√				√				
THIS RESEARCH	√	√	√						√					√		√	√		√												√			√	√	√

2.0 METHODOLOGY

To improve the quality of a product Dr. Genichi Taguchi developed the Taguchi method, an experimental method used to standardize the stages of the experimental design process, as described in Figure 1 (Setyanto and Lukodono, 2017).

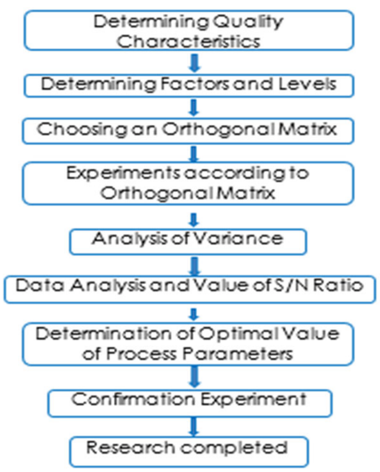

Figure 1 Taguchi experiment design stages

This study considers three factors with three levels at each factor, as shown in Table 2. With three factors and three levels at each factor, the experiment will have six degrees of freedom. Hence, the suitable Orthogonal Array is the $L_9[3^4]$ with nine experiments. This experiment uses three samples for each response. Table 3 shows the complete response tabulation of the experiment in this research.

Table 2 Research factors and levels

Factor	Level
A (glass powder)	4% 8% 12%
B (ash)	4% 8% 12%
C (Placement)	Level 1 Level 4 Level 6

Table 3 Experiment design

Ex.	Factors			Response											
	A	B	C	Resp. 1			` Resp. 2			Resp. 3			Resp. 4		
1	1	1	1	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
2	1	2	2	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
3	1	3	3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
4	2	1	2	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
5	2	2	3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
6	2	3	1	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
7	3	1	3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
8	3	2	1	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
9	3	3	2	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3

S=sample 1,2,3

We used the PCR-TOPSIS to deal with Taguchi multi response. PCR (Process Capability Ratio) is a measurement of a process ability to achieve the design specification. A good process will result in a conformance product with the quality specification represented by the upper specification limit and the lower specification limit. One of the widely used decision making techniques to find a solution is TOPSIS in which the solution has the shortest distance from positive ideal solution and the longest distance from the negative ideal solution. The PCR-TOPSIS is conducted as follows:

a. Calculating SNR value according the quality characteristics.
   - Smaller The Better Response

$$SNR_{stb} = -10 \log \left[\frac{1}{m}\sum_{m=1}^{M}(y_m)^2\right] \quad (1)$$

   - Larger The Better Response

$$SNR_{ltb} = -10 \log \left[\frac{1}{m}\sum_{m=1}^{M}\left(\frac{1}{y_m}\right)^2\right] \quad (2)$$

   - Nominal The Best Response

$$SNR_{ntb} = -10 \log \left[\frac{1}{m}\sum_{m=1}^{M}(y_m - m_0)^2\right] \quad (3)$$

b. Calculating PCR-SNR value of each response from SNR value using Equation (4).

$$PCR - SNR_i = \frac{X_i - \bar{X}}{3S} \quad (4)$$

with $\bar{X}$ = mean

S = standard deviation

c. Determine the normalization matrix by switching weight rate of each alternative to PCR-SNR matrix obtained from the second step.

$$Y_{mn} = W_m . N_{mn} \quad (5)$$

d. Determining positive ideal solution (A^{+}) and negative ideal solution(A^{-}).

$$A^{+} = (Y_1^{+}, Y_2^{+}, \ldots, Y_n^{+}) \quad (6)$$

$$A^{-} = (Y_1^{-}, Y_2^{-}, \ldots, Y_n^{-}) \quad (7)$$

e. Calculating the preference value for each alternative.

$$D_m^{+} = \sqrt{\sum_{m=1}^{n} (Y_m^{+} - Y_{mn})^2} \quad (8)$$

$$D_m^{-} = \sqrt{\sum_{m=1}^{n} (Y_{mn} - Y_m^{-})^2} \quad (9)$$

$$Z_m = \frac{D_m^{-}}{D_m^{+} + D_m^{-}} \quad (10)$$

Where

D_m^{+} for m = 1,2,3..m: distance to-m from the ideal solution

D_m^{-} for m = l,2,3…m: distance to-m from the ideal solution

Y_n^{+} =max {Y_{mn}, for m =l,2,3…i}, n=l,2,3…j)

Y_n^{-} =min {Y_{mn}, for m = 1,2,3…i}, n=1,2,3…j)

Z_m =PCR-TOPSIS value

2.1 ANOVA (Analysis of Variance)

ANOVA is used to test the variation of responses toward the target to find out how much effect caused by the level differences of each factor (main effects) and by internal variation in each level itself (residual error). Equation model of ANOVA can be written as in Equation (11).

$$y_{ij} = \mu + \tau_i + \cdots + \tau_j + \varepsilon_{ij} \quad (11)$$

In that equation, y_{ij} denotes dependent variable, μ is the grand, τ_i denotes the i-th independent variable, ε_{ij} is the residual error which represents the element of y that cannot be explained by μ and τ_j (Gudono, 2016).

It is necessary to test the hypothesis with the F test to determine the significance of the influence of each factor. The results of the F test are arranged into an ANOVA table with the formula as shown in Table 4 (Belavendram, 1995). The percentage of contribution is a value that represents the relative effect of a factor in influencing the responses. The percentage of contribution indicates the relative strength of a factor or interaction in reducing the variation. Total variation can be reduced using the amount indicated through the percentage of contribution (Ross, 1996). if a factor level or interaction is controlled accurately.

Table 4 Analisis of variance (ANOVA)

Source	Sum of Square	degrees of freedom	Mean Square	F-value
Faktor A	SS_A	dfA	MS_A	F_A
Faktor B	SS_B	dfB	MS_B	F_B
Faktor C	SS_C	dfC	MS_C	F_C
Error	SS_E	dfE	MS_E	
Total	SS_T	df		

2.2 Optimal Parameter Determination

The predictive value of the average response under optimal conditions is calculated using Equation (12) (Soejanto, 2009).

$$\hat{\mu} = \mu + (\overline{A_1} - \mu) + (\overline{B_1} - \mu) + (\overline{C_1} - \mu) = \overline{A_1} + \overline{B_1} + \overline{C_1} - 2\mu \quad (12)$$

with $\hat{\mu}$: response prediction value

μ : mean response value

$\overline{A_1}, \overline{B_1}, \overline{C_1}$: mean response value of A_1, B_1, C_1

2.3 Experiment Implementation

Roof tiles made of clay are mixed with glass powder and wood ash are grinded until they are homogenously mixed and become plastic. The production process of the roof tiles uses manual press tool as shown in Figure 2(a). The raw materials of roof tiles that have been processed are put into the mold, then pressed using roof tiles press tool. After being molded, the roof tiles are placed on the shelves for one day, then dried under the sun. After being dried, the burning is carried out in a traditional kiln as shown in Figure 2(b).

(a) (b)

Figure 2 (a) Roof tile press tool and (b) the Kiln

2.4 Response Measurement

The measurement of roof tiles compressive strength is carried out using Computer Universal Testing Machine GT-7001-LCU at Concrete Workshop Laboratory, Faculty of Teacher Training and Educational Sciences Universitas Sebelas Maret (See Figure 3).

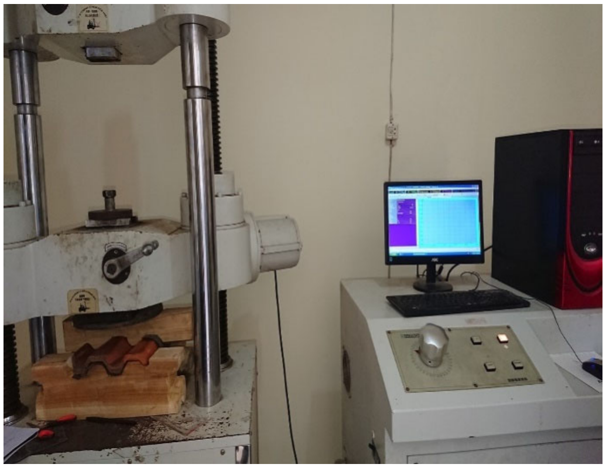

Figure 3 Roof tile compressive strength test

The roof tiles visual testing is conducted by visual observation toward the roof tiles condition, includes arches, cracks, surface condition and color. Visual evaluation is carried out qualitatively (1 = very bad; 2 = bad; 3 = moderate; 4 = good; 5 = very good). Meanwhile for water absorption test, roof tiles are heated in an oven with the temperature of 110 °C for an hour. The mass of each roof tile sample after being heated is stated as dried mass. Then, the roof tiles are soaked in the water for 24 hours until no bubbles occur. Figure 4 shows the soaking process of a roof tile in the water. The roof tiles are then weighed in a wet condition. The water absorbed by the roof tiles is then calculated using Equation (13).

$$\mathrm{Wa} = \frac{\mathrm{Ww-Wd}}{\mathrm{Wd}} \mathrm{x}\ 100\% \qquad (13)$$

Figure 4 Water absorption test

Water permeability testing is carried out by gluing a plastic box on the roof tile surface. One of the surface box sides is adjusted with the roof tile surface, then it is glued on the roof tile surface using cement. After drying, the box is filled to full by water (1200ml). Figure 5 shows the process of water permeability test on the roof tiles. See whether there is permeability six hours later and then the volume of remaining water is measured.

2.5 Determining the Weight Value of Each Response

This study uses four responses that have different weight values, namely compressive strength, visual testing, water absorption test, and water permeability test. The weight value of a response is determined based on the level of importance between one response and another, in this case it is clay roof tile. The weight value of a response can be expressed by the following statement:

a. Very unimportant = 1
b. Not important = 2
c. Quite important = 3
d. Important = 4
e. Very important = 5.

Figure 5 Water permeability test

The weight value consists of numbers from 1 to 5, the higher the weight value of a response, the higher the level of importance of the response in choosing a roof tile product. The weight value of each response is determined subjectively, as follows:

- compressive strength = 5
- visual testing = 5
- water absorption test = 3
- water permeability test = 4.

So that the value of the weight W = (5,5,3,4), respectively for the response of compressive strength, visual testing, water absorption test and water permeability test.

3.0 RESULTS AND DISCUSSION

Table 5 shows the test results for the all responses.

Table 5 The results for the all responses

Nu	Compressive strength Response (Kgf)				Visual Response				Water absorption Response (%)				Water permeability Response (ml)			
	S1	S2	S3	mean	S1	S2	S3	mean	S1	S2	S3	mean	S1	S2	S3	mean
1	403.97	331.19	380.01	371.72	3	4	4	3.67	0.168	0.155	0.160	0.161	370	380	360	370.00
2	50.77	40.19	55.21	48.72	2	4	3	3.00	0.185	0.188	0.186	0.186	340	350	350	346.67
3	89.62	74.57	77.63	80.61	3	4	3	3.33	0.196	0.188	0.191	0.192	550	540	540	543.33
4	88.39	100.78	90.85	93.34	4	5	4	4.33	0.168	0.164	0.167	0.166	240	270	280	263.33
5	74.58	66.62	75.42	72.21	4	4	4	4.00	0.200	0.130	0.165	0.165	420	410	410	413.33
6	223.87	201.71	218.08	214.55	3	3	3	3.00	0.164	0.162	0.160	0.162	400	410	410	406.67
7	90.75	80.61	83.39	84.92	2	5	4	3.67	0.152	0.160	0.160	0.157	420	410	420	416.67
8	54.71	55.27	53.02	54.33	2	3	2	2.33	0.159	0.152	0.156	0.156	250	260	250	253.33
9	64.63	81.78	78.74	75.05	3	5	4	4.00	0.157	0.158	0.158	0.158	390	380	380	383.33
10	46.04	45.8	44.79	45.54	4	4	4	4.00	0.196	0.256	0.225	0.226	390	370	360	373.33

No. 10: conventional roof tile

It can be seen from Table 5 that the greatest value of the compressive strength response is 371.722 Kgf, namely in the experiment No. 1, meanwhile, in concluding that the addition of glass powder and wood ash in the roof tiles production process, as well as the position of the tile on the kiln, can significantly increase the compressive strength of the roof tile, the conventional roof tile has a compressive strength of 45.54 Kgf. The greatest value of the visual testing response was 4.33 in 4th experiment, meanwhile the conventional tile is 4. The smallest value of the water absorption response is 0.1558%, namely in the 8th experiment, meanwhile the conventional tile is 0.2255%, resulting in a significant increase in water absorption response. And the largest value of the water permeability response is 543.3 ml, namely in the 3rd experiment, meanwhile the conventional roof tile is 373.3 ml.

3.1 Signal to Noise Ratio Calculation

SNR value of each response in Table 6 is calculated based on the quality characteristics, smaller the better criteria for water absorption response using Equation (1).

Table 6 SNR value of each response

Exp.	SNR			
	Compressive Strength	Visual Testing	Water Absorption	Water Permeability
1	51.3136	11.040	15.8660	51.3577
2	33.5157	8.5015	14.5940	50.7958
3	38.0478	10.227	14.3521	54.7004
4	39.3602	12.596	15.5834	48.3531
5	37.1300	12.041	15.5132	52.3243
6	46.6049	9.5424	15.8093	52.1830
7	38.5479	9.2996	16.0590	52.3941
8	34.6972	6.9100	16.1471	48.0694
9	37.3654	11.475	16.0543	51.6696

Larger the better for compressive strength, visual evaluation and water permeability using Equation (2). The results of SNR calculation shown in Table 6. A good process will be within ± 3 of standard deviation. The PCR-SNR value is obtained from the transformation of SNR value from each response using Equation (4) as shown in Table 7.

Table 7 PCR-SNR value of each response

Ex.	PCR-SNR			
	Compressive strength	Visual testing	Water absorption	Water permeability
1	0.28925	-0.06098	-0.25147	-0.29879
2	-0.47447	-0.43480	-0.44755	-0.32513
3	-0.27999	-0.18071	-0.48485	-0.14208
4	-0.22368	0.16820	-0.29504	-0.43965
5	-0.31937	0.08645	-0.30586	-0.25347
5	0.08720	-0.28152	-0.26021	-0.26010
7	-0.25853	-0.31727	-0.22172	-0.25020
8	-0.42377	-0.66916	-0.20814	-0.45295
9	-0.30927	0.00307	-0.22244	-0.28417

PCR-SNR values in the Table 7 are then normalized with a certain weight value. In this study, the weight value is assumed to have a value of (5, 5, 3, and 4), respectively, for compressive strength, visual observation, water absorption, and water permeability. The normalization results are shown in Table 8.

TOPSIS method can be used to determine the optimal condition of each factor/level. The analysis result with TOPSIS method is shown in Table 8. The positive (A^+) and negative ideal (A^-) values are obtained as follows:

$$A^+ = \{1.4463;\ 0.8410;\ -1.4546;\ -0.5683\}$$
$$A^- = \{-2.3724;\ -3.3458;\ -0.6244;\ -1.8118\}.$$

Table 8 Normalization of PCR-SNR

Ex.	Normalization of PCR-SNR			
	Compressive strength	Visual testing	Water absorption	Water permeability
1	1.4463	-0.3049	-0.7544	-1.1952
2	-2.3724	-2.1740	-1.3427	-1.3005
3	-1.3999	-0.9036	-1.4546	-0.5683
4	-1.1184	0.8410	-0.8851	-1.7586
5	-1.5969	0.4322	-0.9176	-1.0139
6	0.4359	-1.4076	-0.7806	-1.0404
7	-1.2927	-1.5864	-0.6652	-1.0008
8	-2.1189	-3.3458	-0.6244	-1.8118
9	-1.5464	0.0153	-0.6673	-1.1367

The next step is to determine the value distance weighted toward positive ideal solution (Di^+) and value distance weighted with negative ideal solution (Di^-). The PCR-TOPSIS values are shown in Table 9.

Table 9 PCR-TOPSIS value

Nu	Di^+	Di^-	PCR-TOPSIS
1	1.7162	4.6998	0.7325
2	5.0939	1.1079	0.1787
3	3.4867	2.6651	0.4332
4	2.8931	3.9292	0.5759
5	3.1899	3.4898	0.5224
6	2.8470	3.3249	0.5387
7	3.9523	1.8939	0.3239
8	5.9066	0.6087	0.0934
9	3.3292	3.0736	0.4800

3.2 ANOVA

Software Minitab 18 is used to analyze the ANOVA and the result is shown in Table 10.

Table 10 Analysis of variance

Source	df	SS	MS	F-Value	P-Value	F-Table
Glass powder	2	0.1878	0.0939	7.49	0.004	3.49
Ash	2	0.3430	0.1715	13.67	0.000	3.49
Placement	2	0.2659	0.1330	10.60	0.001	3.49
Error	20	0.2509	0.0125			
Total	26	1.0477				

The Percentage of Contribution

The percentage of contribution is to find out how much contribution is provided by each factor. How much contribution of each significant factor is calculated through the percentage of contribution. The result of the percentage of contribution calculation is shown on Table 11.

Table 11 Contribution percentage calculation result

Source	DF	SS	MS	SS'	contribution (%)
Glass powder	2	0.1878	0.094	0.1627	15.53
Ash	2	0.343	0.1715	0.3179	30.34
Placement	2	0.2659	0.133	0.2409	22.99
Error	20	0.2509	0.0125	0.3262	31.14
Total	26	1.0477			100

From the results of ANOVA in Table 11, it can be seen that ash factor gives the most contribution in influencing the responses (30.34%). The next factor that influences the responses is burning Location factor (22.99%) and glass powder factor (15.53%).

3.3 The Optimal Parameter

The average value of SNR from each level for each response can be seen in Figure 6. The optimal results of each factor/level are shown on Table 12. From Table 12 the optimal parameters setting is $A_1B_1C_1$ (Glass powder factor at level 1, ash factor at level 1, and Location factor at level 1).

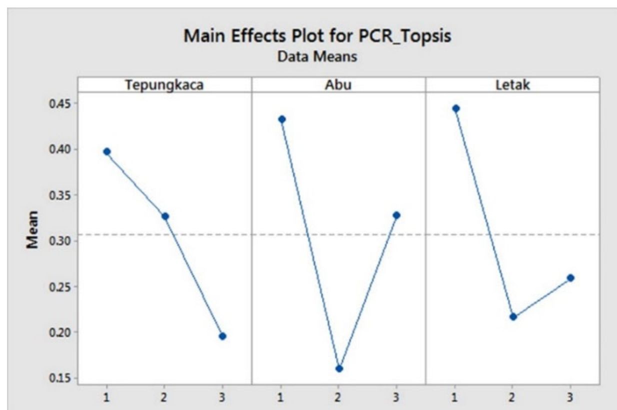

Figure 6 Plot the effect of each factor

Table 12 Optimal results for each factor/level

	Optimal results		
	Glass powder / A	Ash / B	Location / C
Level1	**0.39709**	**0.43314**	**0.44479**
Level2	0.32686	0.15939	0.21627
Level3	0.19582	0.32724	0.25871

4.0 CONCLUSION

In this study, by adding glass powder and wood ash, we carried out the optimization toward the roof tiles production process using four responses, namely compressive strength, visual display, water absorption, and water permeability. From the measurement results of each response, it was concluded that the addition of glass powder and wood ash in the process of roof clay production, as well as variations in the position of the tile on the kiln can increase the compressive strength response, visual testing, water absorption test, and water permeability test.

Based on the results of ANOVA, It can be explained that in the level of significance of 95%, all factors have F values (7.47; 13.67; 10.6) greater than F-Table (3.49; 3.49; 3.49), concluding that glass powder, ash, and Location factors affect the response significantly. The ash factor gives the most contribution in influencing the responses (30.34%). The next factor that influences the responses is the Location factor (22.99%) and glass powder factor (15.53%). Taguchi PCR-TOPSIS Optimization method resulted in optimal combination of factor level combination of $A_1B_1C_1$.

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