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APPLICATION OF TAGUCHI EXPERIMENTAL DESIGN IN THE MANUFACTURING OF CORN COMB BRICK

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ABSTRACT
Utilization for corn cobs as a substitute for aggregate for making bricks, can be used as an environmentally friendly non-structural construction material. This study aims to obtain the optimal composition and quality of bricks. The data collection technique use 36 samples in the form of bricks measuring 30 x 15 x 10 cm, with details of 18 brick samples for compressive strengths testing and 18 samples for wear resistance testing, variations in the addition of corn cobs 5%, 10% and 20%. The data analysis technique used the Taguchi method, with three levels and four factors. The results of the research show that the factors that influence the quality characteristics of the compressive strength and wear resistance of the brick are cement (1.992 kg), corn cobs (0.027 kg) and sand (3.110 kg). With a formulation based on SNR Larger the better at the compressive strength of bricks, namely (A3) cement level 3 and (C1) corn cobs level 1. While the wear resistance results based on Smaller is better are (B3) sand at level 3.

Keywords: *Concrete Bricks; Corn Cob; Taguchi Experiment Design; Compressive Strength; Wear.*

1. Introduction

The use of corn cobs is not only used as animal feed, but the use of corn cobs is also process as an environmentally friendly brick material. It is know that the greater the number of corncobs used, the lower the density of the bricks [1][2]. From the variation of 2.5%, 5%, 10%, the optimum formula was obtained, in the 28-day test which produced an average compressive strength of 31.6 Kg/m² [1]. Corn cobs, which are the processed as brick materials also have good sound absorption [3] . That is due to some of the properties of brick that can be use as a sustainable construction material.

From several studies on the Taguchi method, the optimal composition results with several factors that affect the quality of the bricks suched as sand and lime composition with an average compressive strength of 79.8 kg and an average water absorption capacity of 9.0% [4], the compositioned of water, cement, sand with a ratio of 1:2,5:4, the results of the compressive strength with an average of 18,696 kg/cm² [5], the composition of cement, sand, drying time, the average compressive strength of 4,12 Mpa - 5,43 Mpa [6] , the ratio of water and cement, the average yield of compressive strength is 29.34 N/mm² - 72.21 N/mm² [7], the factors of mixing time, pressure, waters, drying time and lime composition -sand with an average compressive strength of 52.1 kg and an average water absorption capacity of 34.3% which is in accordance with the standard of SNI 03-0349-1989 [8].

Development of corn cobs in the field of sustainable building construction, namely corn cobs as organics lightweight aggregates that may be apply to non-structural construction materials, such as light weight partition wall products and ceiling coatings [9][10][11][12].

2. Method

This research is in the form of a Taguchi experimental design. The sample in this study, amounted to 36 test objects in the form of bricks, measuring 30 x 15 x 10 cm. Variations in the addition of corn cobs by 5%, 10% and 20% [1][12][13]. Test objects made 5% as many as 12 samples, 10% as 12 samples, and 20% as many as 12 samples. Analysis of the tests carried out is the compressive strength and wear resistance of the bricks at the age of 28 days. In this Taguchi experimental design research using four factors and three levels, the factors use are cement, sand, corncobs, and stirring time [14]. While the levels used are composition ratios 1:4, 2:5, and 3:6. From these several factors, the researcher hopes that in carry out a mix designs experimental, they can find out several factors that influence the results of the brick test and produce an optimal combination of compositions.

Figure 1. Dried corn cobs before mashing

Figure 2. Dry corn cobs after mashing

Figure 3. The test object

2.1. Research Flow

Literature study and problem identification were carry out first, determining the materials and compositions be using the next, do a mixed design and make test objects with a predetermined amount, maintain the bricks for 28 days, and test the bricks. Follow by data processing with the final result in the forms of a conclusion.

The following is an illustrations of the research stages which can be seen in Figure 4.

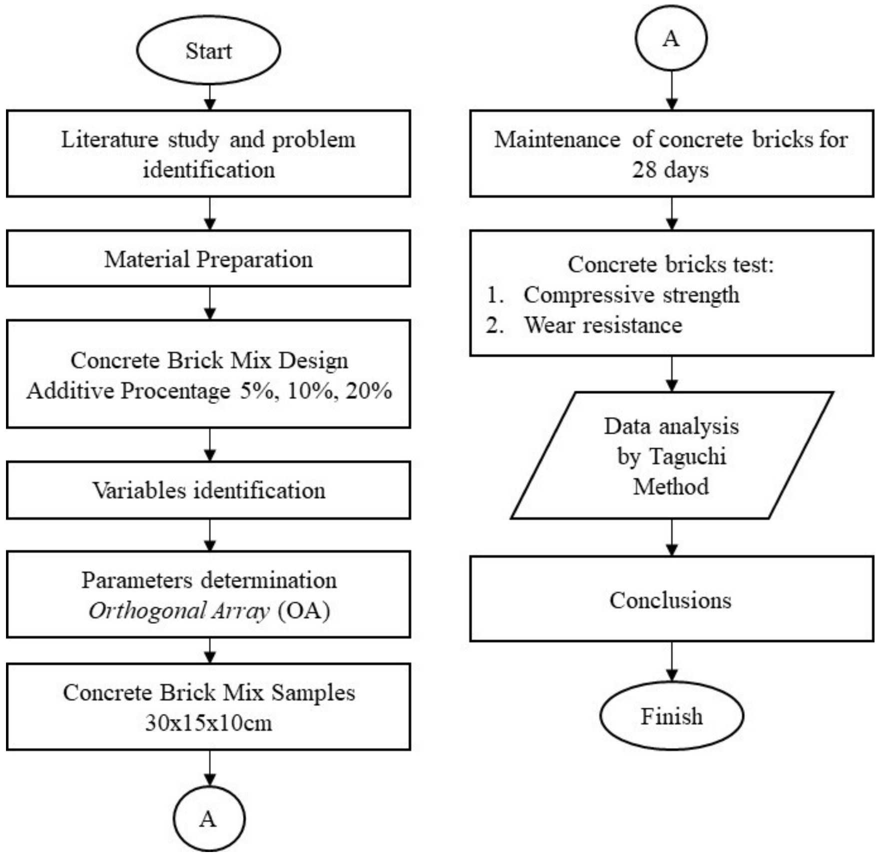

Figure 4. Research Flowchart

2.2. Testing of Test Objects

Used to select factors that have contributed to reducing the variation of response. The S/N ratio consists of several types of quality characteristics, namely:
L larger is better

1. *Larger is better*

   Quality levels with an infinite range of values and with positive results, the higher the yield is the more desirable it [14].

$$S/N = -10log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{{y_i}^2}\right) \quad (1)$$

2. *Smaller is better*

   The lower the result obtained is the expected value [14] .

$$S/N = -10log\left(\frac{1}{n}\sum_{i=1}^{r}{Y_1}^2\right) \quad (2)$$

Where :
n : The number of test objects
y : data obtained from the experiment

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3. Results and Discussion

3.1 Experimental Factors and Levels

There are several factors and levels that will be used as shown in Table 1.

Table 1. Factors and levels

Code	Factor	Level 1	Level 2	Level 3
A	Cement	1,195	1,707	1,992
B	Sand	4,432	3,749	3,110
C	Corn Cob	5%	10%	20%
D	Stir long	5 minutes	10 minutes	15 min

The factors used are 4, among others, cement, sand, corncobs, and the duration of the mix. Each factor has 3 levels of composition, namely level 1 with a composition ratio of 1:4, level 2 with a composition ratio of 2:5, and a ratio of 3:6 at level 3.

3.2 Orthogonal Matrix

The choice of orthogonal matrices is the one that has degrees of freedom higher or equal to the number of degrees of freedom used for this experiment (8 degrees of freedom). So that the orthogonal matrix chosen is L (3) as in Table 2 below [14].

Table 2. Orthogonal matrix L (3)

Ex.	A Cement (kg)	B Sand (kg)	C Corn Cob (kg)	D Stir long (minute)
1.	1 . 195	4 . 432	0 . 027	5
2.	1 . 195	3 . 749	0 . 091	10
3.	1 . 195	3 . 110	0 . 049	15
4.	1 . 707	4 . 432	0 . 091	5
5.	1 . 707	3 . 749	0 . 049	10
6.	1 . 707	3 . 110	0 . 027	15
7.	1 . 992	4 . 432	0 . 027	5
8.	1 . 992	3 . 749	0 . 049	10
9.	1 . 992	3 . 110	0 . 091	15

The orthogonal matrix table consists of 4 factors. Each factor uses 3 different levels. So that the composition formula used for the manufacture of the test object is obtained, as many as 9 experimental combinations.

3.3 Results of Compressive Strength Test and Brick Wear Resistance Test.

Testing the compressive strength of bricks is done by using a Compression Testing Machine. Brick testing was carried out at 28 days of age, with the results as shown in Table 3.

Table 3. The results of the compressive strength of the bricks

Experiment	Compressive Strength Test Results (Mpa)		Average
	I	II	
1	3 . 457	4 . 174	3 . 815
2	2 . 423	3 . 215	2 . 819
3	4 . 160	6 . 047	5 . 104
4	3 . 518	3 . 990	3 . 754
5	3 . 868	2 . 940	3 . 404
6	8 . 260	10 . 187	9 . 223
7	9 . 106	11 . 295	10 . 20
8	7 . 658	5 . 564	6 . 611
9	6 . 162	6 . 400	6 . 281

The higher the compressive strength, the better the quality of the bricks. In the table of compressive strength test results of bricks, the highest results were obtained at an average compressive strength of 10.20 Mpa, with the addition of 5% corn cobs. While the lowest yield on the average compressive strength of 2,819 MPa with the addition of corn cobs of 20%.

Testing for the wear resistance of bricks was carried out using a *Los Angeles tool* at the age of 28 days.

Table 4. The results of the brick wear resistance test

Experiment	Wear Test Results (mm/min)		Average
	I	II	
1	0 . 0041	0 . 0032	0 . 00365
2	0 . 0035	0 . 003 0	0 . 00325
3	0 . 0022	0 . 0006	0 . 00140
4	0 . 0074	0 . 0074	0 . 00740
5	0 . 0019	0 . 0059	0 . 00390
6	0 . 0011	0 . 0011	0 . 00110
7	0 . 0013	0 . 0035	0 . 00240
8	0 . 0009	0 . 0009	0 . 00090
9	0 . 0011	0 . 0030	0 . 00205

In the wear resistance test results, the lowest results were obtained with an average of 0.00090 mm/minute, with a variation of the addition of corn cobs of 10%. The highest wear resistance test results obtained an average of 0.00740 mm/minute, with a variation of 5% corn cobs.

3.4 Analysis of Compressive Strength of Brick

3.4.1 Determination of S/N Ratio Compressive Strength of Brick

The data obtained from the results of the compressive strength test of the bricks were then calculated and the S/N ratio was calculated, the results which can be seen in Table 5.

Table 5. SNR calculation results for the experimental compressive strength of bricks

Ex.	Orthogonal Matrix L (3)				Test Results (Mpa)		SNR
	A	B	C	D	I	II	
1.	1	1	1	1	3 . 457	4 . 174	11 . 516
2.	1	2	3	2	2 . 423	3 . 215	8 . 744
3.	1	3	2	3	4 . 160	6 . 047	13 . 709
4.	2	1	3	1	3 . 518	3 . 990	11 . 438
5.	2	2	2	2	3 . 868	2 . 940	10 . 397
6.	2	3	1	3	8 . 260	10 . 187	19 . 155
7.	3	1	1	1	9 . 106	11 . 295	20 . 022
8.	3	2	2	2	7 . 658	5 . 564	16 . 077
9.	3	3	3	3	6 . 162	6 . 400	15 . 956
				Total			**127 . 015**

From 9 experiments with compositions that match the orthogonal matrix, the results of the compressive strength test were obtained with 2 replicas. While the results of the determination of the S/N ratio of compressive strength are obtained by the formula, as follows [14].

$$S/N = -10log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i{}^2}\right) \quad (3)$$

From the calculation of the S/N ratio of the compressive strength of the bricks from the experimental results, larger the better is determined and the ranking is in Table 6.

Table 6. Response of the S/N ratio and the ranking of the compressive strength of the bricks (*larger is better*)

Level	A	B	C	D
1	11 . 32	14 . 33	16 . 90	14 . 33
2	13 . 66	11 . 74	13 . 39	11 . 74
3	17 . 35	16 . 27	12 . 05	16 . 27
(max – min)	6 . 03	4 . 53	4 . 85	4 . 53
Rank	1	3.5	2	3.5

Factor A, namely cement has the greatest influence on the compressive strength of concrete blocks made from corn cobs added. The best ranking from the selection of the results of the S/N Ratio with the highest level and factor is A3, C1, B3, D3.

3.4.2 Analysis of variance compressive strength of bricks

Table 7. ANOVA and percent contribution to the compressive strength of bricks

Source	V	SS	MS	F-Ratio	p(%)
A	2	55 . 43	27 . 713	3 . 55	44 . 59
C	2	37 . 63	18 . 816	2 . 41	30 . 27
Error	4	31 . 24	7 . 81		
Total	**8**	**124 . 3**			

From the ANOVA table, there are significant factors, namely factor A (cement) and factor C (corn cob), and it is known that the results are V (degree of freedom), SS (sum of the square), MS (mean square), F-Ratio and percent contribution of p. (%).

3.5. Brick Wear Resistance Analysis

3.5.1. Determination of S/N Ratio of Brick Wear Resistance

The data obtained from the test results of the brick samples were then calculated for the S/N ratio in the wear resistance test, which can be seen in Table 8 below.

Table 8. SNR calculation results for wear resistance experiments

Ex.	Orthogonal Matrix L (3)				Wear Test Results		SNR
	A	B	C	D	I	II	
1.	1	1	1	1	0 . 0041	0 . 0032	48 . 6886
2.	1	2	3	2	0 . 0035	0 . 003 0	49 . 7367
3.	1	3	2	3	0 . 0022	0 . 0006	55 . 8503
4.	2	1	3	1	0 . 0074	0 . 0074	42 . 6154
5.	2	2	2	2	0 . 0019	0 . 0059	47 . 1647
6.	2	3	1	3	0 . 0011	0 . 0011	59 . 1721
7.	3	1	1	1	0 . 0013	0 . 0035	51 . 5677
8.	3	2	2	2	0 . 0009	0 . 0009	60 . 9151
9.	3	3	3	3	0 . 0011	0 . 0030	52 . 9200
				Total			**468 . 6307**

The results of the wear resistance test of 18 samples, determined the S/N ratio of the wear resistance with the formula below [14] .

$$S/N = -10log\left(\frac{1}{n}\sum_{i=1}^{r} Y_1{}^2\right) \quad (4)$$

From the calculation of the S/N ratio of the wear resistance of the bricks from the experimental results, the determination of Smaller is Better (the smaller the better) and ranking is carried out as shown in Table 9.

Table 9. Response of S/N ratio and ranking of brick wear resistance *(smaller is better)*

Level	A	B	C	D
1	51 . 43	47 . 62	53 . 14	47 . 62
2	49 . 65	52 . 61	54 . 64	52 . 61
3	55 . 13	55 . 98	48 . 42	55 . 98
(max - min)	5 . 48	8 . 36	6 . 22	8 . 36
Rank	4	1.5	3	1.5

From the table above, with the smaller formulation, the better, the results obtained for factors B (sand) and D (long mix), at level 3.

3.5.2. Analysis of variants of Brick Wear Resistance

From the calculation of the analysis of the wear resistance variance, the results are shown in Table 10.

Table 10. ANOVA and percent contribution to brick wear resistance

Source	V	SS	MS	F-Ratio	p(%)
B	2	106	53 . 02	1 . 89	38 . 67
Error	6	168	28 . 04		
Total	**8**	**274.3**	**81 . 06**		

From Table 10, the most significant factor obtained is factor B (sand). And from the calculation of the analysis of variance can be seen the results of V (degree of freedom), SS *(sum of the square)*, MS *(mean square)*, F-Ratio and percent contribution of p (%) wear resistance.

3.6. Optimal Composition Results

From the analysis of the data processing of the compressive strength and wear resistance test results using the Taguchi method, the optimal composition results are obtained based on the response of the S/N ratio and ranking, as shown in Table 11. below.

Table 11. The optimal composition of the compressive strength and wear resistance of the bricks

	Influential factors	Level 1	Level 2	Level 3
Strong Press	Cement	1 . 195 kg	1 . 707 kg	1 . 992 kg
	Corn Cob	5%	10%	20%
wear	Sand	4,432 kg	3,749 kg	3.110 kg

Information:
Yellow = Combination of optimal compressive strength composition
Green = Combination of optimal wear resistance composition

4. Conclusion

Based on the results of research and analysis that has been carried out, it can be concluded that the indications of factors that influence the S/N ratio of the compressive strength of bricks include the combination of factor A (cement) with a composition of 1,992 kg at level 3 (A3) and factor C (corn cob) with a composition of 5% (0.027 kg) at level 1 (C1). Meanwhile, for the optimum wear resistance test results, the influencing factor is factor B (sand) 3.110 kg at level 3 (B3).

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