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A Model Experiment Design Using the Taguchi Method: A Case Study Of Making Concrete Roof

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ABSTRACT

This research was conducted at a company manufacturing paving blocks, ceramics, ventilation, concrete, and roof tiles. This study aims to improve the quality of concrete tile products, which experience the most cracks and breaks. Research to determine the composition of concrete roof tiles can be carried out by design experiments using the Taguchi method. This experiment used raw materials such as cement, sand, milled flour, and water. The concluding results show that the quality of concrete roof tiles is based on the results of the Taguchi method and confirmation experiments, which are characterized by an increase in the compressive strength of the concrete tile based on the average value (μ) and its variability (SNR). The average compressive strength (μ) of concrete roof tiles increased from 19.814 ≤ 21.208 ≤ 22,602 in the Taguchi experiment to 26.406 ≤ μconfirmation ≤ 29.894 in the confirmation experiment. While the variability (SNR) increased from 25.532 ≤ 27.521 ≤ 29.510 in the Taguchi experiment to 26.473 ≤ S/N confirmed ≤ 31.469 in the confirmation experiment. The optimal composition of cement, sand, milled flour, and water that produces the best compressive strength based on the response factor and SNR is 0.9 kg: 0.5 kg: 0.4 kg: 0.3 kg, respectively. The most influential factors on the compressive strength of concrete roof tiles are the amount of sand and the number of flour mills.

Keywords: Concrete tile, Experimental design, Taguchi

INTRODUCTION

Concrete tile is a building element used for the roof, and the roof is made of an even mixture of cement, sand, or the like with aggregate and water with or without using other additions. Along with this, the demand for quality and product quality is also increasing [1]. Thus, it requires concrete tile manufacturers to be able to maintain and improve the quality of the products produced [2].

PT X is a company engaged in manufacturing concrete tiles, paving blocks, ceramics, breezeblock, and riol. The primary raw materials for making concrete tiles are cement, sand, mill flour, and water. The adhesive used is red and white, commonly used for public buildings that do not have special requirements for mixing raw materials. The sand used comes from mountain sand. In addition to cement and sand, the manufacture of concrete tiles also uses mill flour, which serves as an additional mixture for making concrete tiles.

The problem that often occurs in the concrete tile production process is that products are easily broken due to the compressive strength of concrete tiles that do not comply with predetermined specifications—defects found in concrete tile products in the form of cracks, plugs, or cuts, and breaks [3]. Thus, further research will be carried out on the factors that affect the most optimal composition of concrete tiles and the things that cause defects in concrete tile products and combinations by conducting experimental designs through the Taguchi method approach. So far, the company has only determined the standard content of each ingredient but has not found the most optimal range [4][5]. Table 1 shows the grade standards for each concrete tile production.

Table 1. The Standard Grade of Each Concrete Tile Production.

Material	Minimum	Usual	Maximum
Cement	100 Kg	120 Kg	135 Kg
Sand	35 Kg	40 Kg	47 Kg
Flour Mill	42 Kg	40 Kg	60 Kg
Water	15 Liter	20 Liter	20 Liter

The method used in this study is the Taguchi method. This method serves as an experimental procedure for designing parameters that state the values or settings of variables that can be controlled and set so that variations caused by several interference factors can be minimized [4]. The Taguchi method is very suitable for optimizing quality characteristics and can be applied well to maximize the interaction of machining processes such as surface roughness[7][5]. The Taguchi method can also be used to optimize some experimental factors in the industry [6].

This study aims to identify the factors most significantly influencing the strength of concrete roof tiles and determine the best combination and composition of raw materials to produce the optimum compressive strength of concrete roof tiles with an experimental design.

Conducting experimental designs through this Taguchi method approach is expected to determine the factors that affect the compressive strength of concrete tiles and produce the right combination and composition of raw materials that provide the maximum compressive strength of concrete tiles desired by consumers and provide quality improvements to the products paid [7][8][11].

METHOD

The type of research used is experimental design research. This study aims to determine the most significant cause of failure in making concrete tiles and make improvements by selecting the composition of concrete tiles with the best compressive strength [9][10][13]. The factors that affect the strength of concrete tile are the amount of cement, sand, mill flour, and water. The best composition can be used as a definite tile composition to improve the strength quality [1], [8], [10], [11], [14]–[16]. The conceptual framework formed by the relationships between variables in the study is shown in Figure 1.

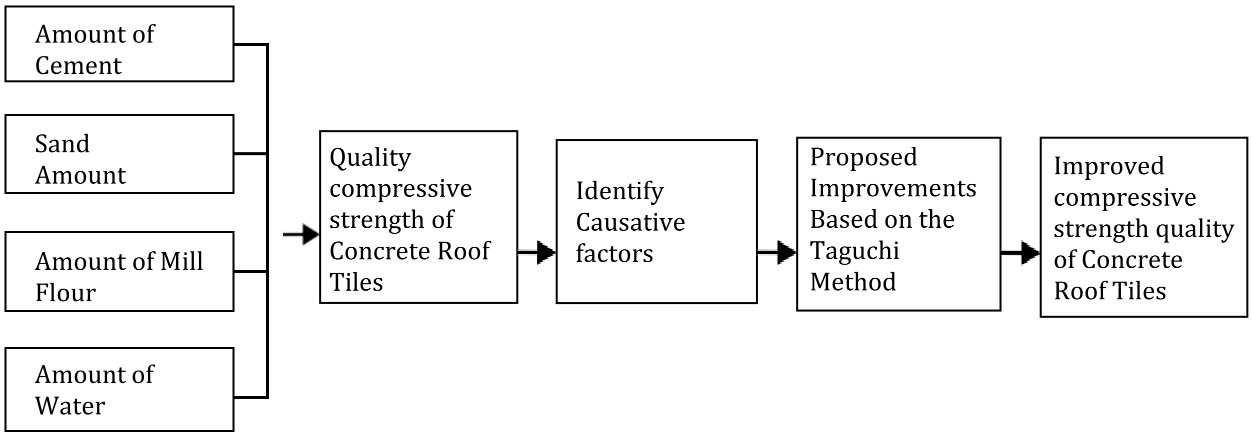

Figure 1. Research Conceptual Framework

Research Procedure Design

The research was carried out by following steps such as a preliminary study to find out the company's condition, the production process, and the necessary supporting information, as well as a survey of the literature on the problem-solving method used and other supporting theories—then data collection techniques, data processing, and so on [17]–[22].

Data Collection Techniques

Data collection techniques in this study were carried out by [6], [13], [23]–[25]:

1. Observation is collecting data using direct words of the object under investigation to obtain relevant data.
2. Conduct interviews with leaders and employees to obtain more accurate and actual data.
3. A literature study is conducting a literature study of various books on the problems observed in the company.

Data Processing Techniques

Data processing was carried out using the Taguchi experimental design, which has stages from the preparation stage to the implementation of the experimental results. The block diagram of data processing using the Taguchi method is shown in Figure 2 [26]–[30].

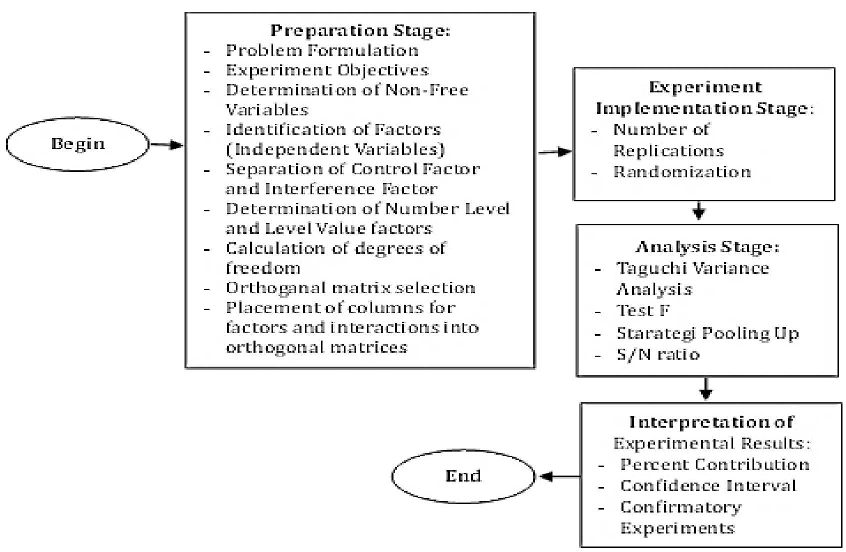

Figure 2. Diagram of Data Processing

RESULTS

Experimental Planning with the Taguchi Method

1. Identification of Non-Free Variables
   The non-free variable injected in this study is the compressive strength of concrete tiles. The characteristics used are more significant, which means that the higher the strength of the concrete tile, the better the quality.
2. Control Factor Identification
   The results of the identification of controllable factors are shown in Table 2.

Table 2. Control Factors

No	Code	Factor
1	A	Cement
2	B	Sand
3	C	Flour Mill
4	D	Water

Determining the Number of Levels and Factor Level Values

The level of each factor shown in Table 3 can be determined from the alternatives to controllable factors.

Table 3. Level and Factor Level Values

Code	Control Factors	Level 1	Level 2
A	Cement	0.9 kg	1.5 kg
B	Sand	0.3 kg	0.5 kg
C	Flour Mill	0.4 kg	0.7 kg
D	Water	0.3 ltr	0.5 ltr

The determination of this level is carried out on the consideration of:
a. The value of each level is still within the range set by the company.
b. Level points that show extreme values.
c. The level can still be handled by existing process technology.

Design of Experiment

This study uses four factors, A, B, C, and D, and has two levels with a degree of freedom value of 4. The orthogonal matrix used for this study was L8(2,^{7}). Table 4 shows the complete randomized series of combinations of each experiment.

Table 4. Complete Randomized Circuit Combination of Each Experiment

Experiments	Factor							Compressive Strength of Roof TileConcrete (kg/cm2)			Sum	Average
	1	2	3	4	5	6	7					
	A	B	C	D	e	e	e					
1	1	1	1	1	1	1	1	18.5	18	18	54.5	18.167
2	1	1	1	2	2	2	2	20.5	20.5	20	61	20.333
3	1	2	2	1	1	2	2	20	19.5	19	58.5	19.5

4	1	2	2	2	2	1	1	17	17.5	17	51.5	17.167
5	2	1	2	1	2	1	2	18	18.5	19.5	56	18.667
6	2	1	2	2	1	2	1	16.5	17	17	50.5	16.833
7	2	2	1	1	2	2	1	20.5	21.5	22.5	64.5	21.5
8	2	2	1	2	1	1	2	24	21	20.5	65.5	21.833
Sum											462	154
Average											57.8	19.25

Calculating the S/N Ratio

The characteristics used are Larger and Better, so what is expected is the highest compressive strength of concrete tiles. The quality characteristic that is the goal of quality improvement is to maximize the compressive strength of concrete tiles. Power has quality characteristics. The higher the compressive strength value of concrete tile, the better. The experimental results and calculation of the S/N ratio can be seen in Table 5.

Table 5. Experimental Results and S/N Ratio

	Factor							Replication (kg/cm2)			S/N Ratio
	1	2	3	4	5	6	7				
Experiment	**A**	**B**	**C**	**D**	**e**	**e**	**e**	I	II	III	
1	1	1	1	1	1	1	1	22.5	21	19.5	25.183
2	1	1	1	2	2	2	2	20.5	20.5	20	26.162
3	1	2	2	1	1	2	2	20	19.5	19	25.795
4	1	2	2	2	2	1	1	24.5	26	23.5	24.691
5	2	1	2	1	2	1	2	18	18.5	19.5	17.19
6	2	1	2	2	1	2	1	17	18.5	17.5	24.521
7	2	2	1	1	2	2	1	20.5	21.5	22.5	26.629
8	2	2	1	2	1	1	2	24	21	20.5	26.721

Analysis Average Variance of Compressive Strength of Concrete Roof Tiles

The calculation of ANAVA below is to perform a two-way variance analysis model consisting of calculating degrees of freedom, the number of squares, the average number of courts, and the F-ratio. Table 6 shows the percent contribution.

Table 6. Person Contributions

Source	V	SS	MS	F-Ratio	SS'	ρ(%)
A	1	1.68	1.68	0.41	-2.43	-9.11
B	1	4.5	4.5	1.39	2.38	8.92
C	1	11.68	11.68	3.62	9.56	35.83
D	1	0.34	0.34	0.08	-3.77	-14.13
Error	6	24.66	4.11	-	-	-
Total	10	26.84	20.32	-	-	-

Optimal S/N ratio prediction

It is known that the factors that significantly affect the average compressive strength of optimum concrete tile are:

Factor C level 1 (Mill flour 0.4 kg) Factor B level 2 (Sand 0.5)
So the model equation is:
μprediction = Y + (C1−Y) + (B2−Y)
= 24.612 + (26.174 – 24.612) + (25.959–24.612)
= 27.521

DISCUSSION

In the confirmation experiment, factors and levels were determined, such as factors and levels at optimal conditions, namely the Cement factor of 1.5 kg at level 2 (A2), sand 0.5 kg at level 2 (B2), mill flour 0.4 kg at level 1 (C1) and Water 0.3 ltr at level 1 (D1). For confirmation, ten samples were taken with levels at optimum conditions. These results are in line with research [31]. His study found improvement solutions to improve the quality of lightweight bricks at UD. XY is by conducting an experimental design using the Taguchi method. The experimental results for the optimal light brick composition obtained are water:cement: sand composition of 1:2.5:4. A confirmation experiment was carried out to ensure the composition results are robust. The results of the confirmation experiment showed an increased average compressive strength and a minimal variance (0.041) compared to the initial condition variance (31.68). [32] research also indicates that compressive strength influences the volume ratio between the foam and the sand and geopolymer paste mixture. The optimum composition is obtained by combining the ratio of sand to geopolymer paste of 1:1, the percentage of foam to sand and paste of 1:1, and the curing temperature of 25 oC, resulting in a maximum compressive strength value of 63 kg/cm2. From the calculation of the confidence interval at the 90% confidence level for the Taguchi experiment and then compared with the confidence interval for the confirmation experiment, it was found that the average in the confirmation experiment was at the confidence interval of the Taguchi experiment. The confidence interval can be seen in Table 7.

Table 7. Interpretation of Concrete Tile Compressive Strength Measurement Results

Response (compressive strength of concrete tiles)	Predictions		Optimization
Experiment	Average (μ)	21.208	21.208 ± 1.394
Taguchi	Variability (S/N)	27.521	27.521 ± 1.989
Experiment	Average(μ)	28.15	28.150 ± 1.744
Confirmation	Variability (S/N)	28.971	28.971 ± 2.498

Based on the interpretation of the results of the calculation of compressive strength of concrete tiles listed in Table 7, namely Taguchi's experiment to experiments and confirmation of an increase in average and variability. Thus, the optimal combination of factors mentioned above is proven to increase the compressive strength of concrete tiles. This is the same as the results of the [33] study, where it can be concluded that the percentage of defects that occurred at the company was initially around 4%. In contrast, the rate of application results using the Taguchi method decreased to 2%. A decrease in the percentage of defects means an increase in product quality. The factor that most influences the quality of the product is the drying process time, with the most significant contribution percentage value of 34.5%.

CONCLUSION

Based on the indication of factors, the factors that affect the compressive strength of concrete tiles are cement (A), Sand (B), Mill Flour (C), and Water (D). Based on the comparison between the F-ratio and F-table on the pooling up strategy shows that the factors that significantly affect the compressive strength of concrete tiles are factor B (amount of sand) and factor C (amount of mill flour). The combination of the level of the factor that produces the average value and the optimal compressive strength variance of concrete tile is the same, which is obtained from setting the sand factor at level 2 of 0.5 Kg (B2) and mill flour at level 1 of 0.4 Kg (C1). Based on the response of the influence of factors and signals to Noise Ratio, the best composition is obtained from the comparison of factor A (cement), factor B (sand), factor C (mill flour), and factor D (Water) respectively is level 1 (0.9 kg): Level 2 (0.5 kg): Level 1 (0.4 kg): Level 1 (0.3 kg). Based on the results of the interpretation of the results of the calculation of compressive strength of concrete tiles, the results of experiments with the Taguchi method to confirmatory experiments have increased in the average value (μ) and variability (SNR). So, it is proven that the optimal combination of factors can increase the compressive strength of concrete roof tiles.

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