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Experimental Study on The Application of Taguchi Design of Experiment (DoE) and ANOVA for a Waste-Based Composite Material

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ABSTRACT

The increasing amount of industrial and agricultural waste necessitates innovation in the use of environmentally friendly alternative materials in the construction sector. This research aims to analyze the influence of varying cement, sand, seashell powder, and coconut fiber powder compositions on the compressive strength and porosity of paving blocks using the Taguchi method and ANOVA. The experimental design uses an orthogonal array L16 (4^4), resulting in 16 experimental combinations. The test results indicate that coconut husk powder is the most significant factor influencing porosity, while other factors have a relatively small effect. The optimum parameters for porosity were obtained at a cement composition of 643.24 g, sand 915.84 g, seashell powder 686.883 g, and coconut fiber powder 0 g. Meanwhile, the optimum compressive strength was achieved at cement 643.23 g, sand 2289.60 g, seashell powder 228.961 g, and coconut fiber powder 0 g. Regression analysis showed that the model had a good fit with an R^2 of 0.8967 for porosity and 0.5625 for compressive strength. This research proves that utilizing clamshell and coconut husk waste has the potential to produce high-quality paving blocks while also supporting sustainable waste management.

Keywords: *Taguchi Anova Method; Paving Block; Compressive Strength; Shell Powder; Coconut Fibre Powder.*

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ABSTRACT

Peningkatan jumlah limbah industri dan pertanian mendorong perlunya inovasi pemanfaatan material alternatif yang ramah lingkungan dalam bidang konstruksi. Penelitian ini bertujuan untuk menganalisis pengaruh variasi komposisi semen, pasir, serbuk cangkang kerang, dan serbuk sabut kelapa terhadap kuat tekan dan porositas paving block dengan metode Taguchi dan ANOVA. Desain eksperimen menggunakan orthogonal array L16 (4^4) sehingga diperoleh 16 kombinasi percobaan. Hasil pengujian menunjukkan bahwa faktor serbuk sabut kelapa memiliki pengaruh paling signifikan terhadap porositas, sedangkan faktor lain memberikan pengaruh relatif kecil. Parameter optimum untuk porositas diperoleh pada komposisi semen 643,24 g, pasir 915,84 g, serbuk cangkang kerang 686,883 g, dan serbuk sabut kelapa 0 g. Sementara itu, kuat tekan optimum dicapai pada semen 643,23 g, pasir 2289,60 g, serbuk cangkang kerang 228,961 g, dan serbuk sabut kelapa 0 g. Analisis regresi menunjukkan model memiliki kecocokan baik dengan R^2 0.8967 untuk porositas dan 0.5625 untuk kuat tekan. Penelitian ini membuktikan bahwa pemanfaatan limbah cangkang kerang dan sabut kelapa berpotensi menghasilkan paving block dengan kualitas baik sekaligus mendukung pengelolaan limbah secara berkelanjutan.

Keywords: *Metode Taguchi Anova; Paving Block; kuat Tekan; Cangkang kerang; serbuk Serat Kelapa.*

INTRODUCTION

The increasing generation of industrial and agricultural waste has become a major environmental challenge, particularly in coastal and agricultural regions of Indonesia. In East Java, especially along the northern coast of Gresik Regency and surrounding areas such as Tuban and Lamongan Regency, green mussel cultivation produces a large quantity of shell waste, while coconut processing activities generate abundant coconut fruit peel waste that is still underutilized. If not properly managed, these wastes can contribute to environmental pollution [1][2]. Therefore, innovative approaches are required to convert such waste materials into value-added products, particularly in the construction sector.

One promising approach is the development of waste-based composite materials. Composite materials are engineering materials formed by combining two or more distinct constituents—typically a matrix and a reinforcement—to produce a material with improved properties compared to those of the individual components. In cement-based composites, cement paste acts as the matrix, while aggregates or fibers function as reinforcement, enhancing mechanical strength, durability, and other performance characteristics. In this study, paving blocks are treated as composite materials in which cement serves as the binder matrix, sand as the primary aggregate, and green mussel shell powder together with coconut fiber powder as secondary reinforcing and filler materials. The incorporation of these wastes not only modifies the internal structure of the composite but also influences key properties such as porosity and compressive strength.

Previous studies have reported that seashell or clam shell powder can improve compressive strength when used as an additive, while excessive substitution of natural aggregates may increase water absorption [3][4][5]. Similarly, coconut fiber or coconut husk powder has been shown to affect porosity and strength depending on its proportion in the mixture. These findings indicate that the performance of waste-based concrete composites is highly dependent on material composition, and improper proportions may lead to reduced strength or durability [6][7]. Consequently, identifying the optimal combination of cement, sand, shell powder, and coconut fiber powder is a critical challenge. Furthermore, adding coconut fiber powder as an aggregate (sand) mixture to increase water absorption or porosity with a specific composition produces paving blocks that are close to the quality standards of SNI 03-0691-1996 [8][9].

Two important parameters that serve as benchmarks for quality are compressive strength and porosity. Compressive strength indicates the ability of paving blocks to withstand loads, while porosity is related to the density and water absorption capacity. The higher the compressive strength and the lower the porosity, the better the quality of the resulting paving blocks [10][11]. The main challenge in utilizing waste as a paving block mix is determining the correct material composition. An incorrect composition can reduce quality, both in terms of strength and durability. Therefore, an effective experimental approach is needed to evaluate the influence of material composition factors on the characteristics of paving blocks.

The Taguchi method is one of the experimental design techniques that can reduce the number of experiments while still producing comprehensive information [12][13]. By using an orthogonal array, this method allows researchers to study the influence of multiple factors simultaneously with a more efficient number of experiments. Analysis of variance (ANOVA) was then used to test the significance of each factor's effect on the response [13]. By combining these two methods, the dominant factors influencing the quality of paving blocks can be determined, and the optimal material composition can be obtained. This approach not only streamlines the experimental process but also enhances the reliability of the results. Ultimately, the findings can lead to improved manufacturing techniques and better-performing paving blocks in various applications [14].

Considering the research that has been conducted and its developments [1][2], the urgency of this research is focused on analyzing the influence of variations in four main factors, namely cement, sand, seashell powder, and coconut fiber powder, on the compressive strength and porosity of paving blocks. The research was conducted experimentally and applied the Taguchi ANOVA method analysis to obtain the optimal percentage composition between the combination of green seashell and coconut fiber powder materials for cement, aggregate (sand), and water mixtures to provide an overview of the most influential parameters, determine the best mixture combination, and contribute to the development of waste-based building material technology. Additionally, the results of this research are expected to serve as a reference in supporting the concept of sustainable construction and more productive waste management in the future.

METHOD AND MATERIALS

This research uses experimental processes and analysis, while the experimental data analysis applies the Taguchi ANOVA experimental approach to determine the optimal mixture composition for paving block production in terms of compressive strength and water absorption (porosity) tests. This research has several stages, including the design of experiments, data collection, and statistical analysis to evaluate the results. All the data processing used minitab17.

1. Determination of Mixture Composition Parameters

The common cement-to-sand mixture ratios used are 1:3, 1:4, and 1:5 [5][15] . This study uses the SNI 03-0691-1996 quality standard [16][17] with the following provisions :

a. Material composition: 1 part cement to 3 parts sands, where the sand is mixed with green mussel shells and coconut fiber powder in varying percentages of 0%, 10%, 20%, and 30%.
b. Manual pressing with a mold size of 20 cm x 10 cm x 8 cm.
c. Test specimen volume requirements are as follows: 20cm x 10cm x 8cm = 1600cm³.
d. Mixing factor: if compaction fills the empty spaces, 1.2 x 1600 cm³ = 1920 cm³.
e. Assumptions for cement and sand requirements at a ratio of 1:3 are as follows:
   1. The cement requirement is ¼ of 1920 cm³, or 480 cm³.
   2. The sand requirement is ¾ of 1920 cm³, or 1440 cm³.
f. Cement and sand requirements for the volume of the test specimen:
   1. Cement has a bulk density of 1.34 grams/cm³, so 480 cm³ x 1.34 gram/cm³ = 643.2 gram[18].
   2. Sand has a bulk density of 1.59 grams/cm³, so 1440 cm³ x 1.59 gram/cm³ = 2289.6 gram [19][20].

subsequently, the data on the composition of the paving block manufacturing material mixture 1:3 is shown in Table 2 below;

Table 1. Composition ratio of paving block materials.

Percentage of the Green Shell Powder and the Coconut Fiber Powder	Cement (g)	Sands (g)	the Green Shell Powder (g)	the Coconut Fiber Powder (g)
0%	643,2	2289,6	0	0
10%	643,2	1831,68	228,96	228,96
20%	643,2	1373,76	457,92	457,92
30%	643,2	915,84	686,88	686,88

2. Composition Mapping using the Taguchi Method

The experimental design in this study utilizes the Taguchi method with a four-factor and four-level configuration, including cement, sand, green mussel shell powder, and coconut fiber powder, each with four variations in composition levels, using an Orthogonal Array (OA). OA enables researchers to study the influence of multiple control parameters simultaneously with a minimal number of experiments [21]. This design employs the orthogonal array (OA) L16 (4^4) approach, reducing the number of experiments to 16 while still representing all parameter combinations equally and more efficiently to determine the influence of each factor on the compressive strength and porosity of paving blocks, as well as to identify the resulting optimum conditions [22]. The composition data results are presented in Table 2 as follows:

Table 2. Composition Mapping Results

No. Observation	Factor			
	Cement (gram)	Sands (gram)	The Green Shell Powder (gram)	The Coconut Fiber Powder (gram)
1	643.21	2289.60	0.000	0.000
2	643.21	1831.68	228.961	228.960
3	643.21	1373.76	457.922	457.921
4	643.21	915.84	686.883	686.881
5	643.22	2289.60	228.961	457.921
6	643.22	1831.68	0.000	686.881
7	643.22	1373.76	686.883	0.000
8	643.22	915.84	457.922	228.960
9	643.23	2289.60	457.922	686.881
10	643.23	1831.68	686.883	457.921
11	643.23	1373.76	0.000	228.960
12	643.23	915.84	228.961	0.000
13	643.24	2289.60	686.883	228.960
14	643.24	1831.68	457.922	0.000
15	643.24	1373.76	228.961	686.881
16	643.24	915.84	0.000	457.921

3. Paving Block Manufacturing and Maintenance

Process During the specimen manufacturing process, all materials were mixed and stirred until evenly distributed according to the proportions planned in Table 2. Then, the mixture was molded and pressed manually using a tool until it hardened. After hardening, the process is followed by sun drying for 24 hours for 28 days.

4. Porosity Tests

Water absorption testing was conducted by immersing paving blocks in water for 24 hours, then weighing them and recording the wet weight data. This was followed by oven drying at 100°C for 24 hours, as shown in the figure below:

Figure 1. Porosity Test Documentation

after which the specimens were weighed and the dry weight data recorded [4][6], to obtain the porosity value using the following formula:

$$\frac{(mb-mk)}{mk} x\ 100\% \qquad \text{.... (1)}$$

Where: mb = wet mass when soaked in water, mk = dry mass after oven drying for 24 hours

5. Compression Test

Compressive strength testing is a standard procedure for measuring the maximum strength of paving blocks in withstanding compressive loads until they break. The compressive strength testing procedure and testing diagram are as follows:

1. The dimensions of the dry paving block samples are measured.
2. They are placed in a hydraulic press.
3. A load is applied, increasing slowly and constantly until the sample breaks.
4. The maximum load at failure is recorded.

Figure 2. Compressive strength Test Documentation

Compressive strength is calculated using the following formula [22],

$$\sigma = \frac{P}{A} \qquad \text{..... (2)}$$

Where, σ (sigma) = Compressive Strength (in MPa or N/mm²), P = Maximum Load when the paving block breaks (in Newtons, N), A = Cross-sectional area receiving the load (in mm²). For paving blocks, this is usually calculated from length x width.

RESULTS AND DISCUSSION

1. Design Parameters and Levels of Paving Blocks

The current study employs four main factors that influence the paving block manufacturing process: cement, sand, seashell powder, and coconut fiber powder. Each factor is set at four different levels to produce variations in material composition, with the goal of analyzing the impact of material combinations on the quality of the resulting paving blocks. The details of the research parameters and levels are presented in Table 3 below.

Table 3. Paving Block Parameters and Levels

Parameters	Levels			
	1	2	3	4
Cement (g)	643.21	643.22	643.23	643.24
Sand (g)	2289.60	1831.68	1373.76	915.84
The Green Shell Powder (g)	0.000	228.961	457.922	686.883
The Coconut Fiber Powder (g)	0.000	228.960	457.921	686.881

2. Combination of Compression and Porosity Test with the Taguchi Method

All combinations of factors and levels determined through the Taguchi method experimental design were then tested to determine the characteristics of the resulting paving blocks. The testing focused on two main parameters, compressive strength and porosity, as both are important indicators in assessing the quality and durability of paving blocks. The results of each treatment combination are presented alongside the compressive strength and porosity test values. Detailed data can be seen in Table 4 below.

Table 4. Results of Combination, Compression Test, and Porosity

No. Observation	Factor				Porosity (%)	Compressive strength (MPa)
	Cement (g)	sand (g)	The Green Shell Powder (g)	The Coconut Fiber Powder (g)		
1	643.21	2289.60	0.000	0.000	8	11.28
2	643.21	1831.68	228.961	228.960	9	10.06
3	643.21	1373.76	457.922	457.921	9.71	8.84
4	643.21	915.84	686.883	686.881	10	8.72
5	643.22	2289.60	228.961	457.921	9.59	8.72
6	643.22	1831.68	0.000	686.881	9.59	8.68
7	643.22	1373.76	686.883	0.000	8.18	8.76
8	643.22	915.84	457.922	228.960	9	9.21
9	643.23	2289.60	457.922	686.881	9.88	8.72
10	643.23	1831.68	686.883	457.921	9.41	8.8
11	643.23	1373.76	0.000	228.960	9.18	9.55
12	643.23	915.84	228.961	0.000	8.06	12.5
13	643.24	2289.60	686.883	228.960	8.24	9.39
14	643.24	1831.68	457.922	0.000	8.18	9.15
15	643.24	1373.76	228.961	686.881	9.76	8.72
16	643.24	915.84	0.000	457.921	9.82	8.5

3. The Calculation of Signal-to-Noise Ratio

Following the acquisition of compressive strength and porosity test data from each experimental combination, the next step is to calculate the Signal-to-Noise (S/N) ratio. This calculation aims to evaluate response quality by minimizing the effect of data variation. The "larger-the-better" category is used for compressive strength, where a higher value indicates better performance, while the "smaller-the-better" category is applied to porosity, as a lower value signifies higher quality paving blocks [23][24]. The Signal-to-Noise (S/N) ratio is calculated to determine the optimal control parameter settings that minimize the effect of noise. The specific formula applied depends on the quality characteristic of the response variable.

For a characteristic where a larger value is more desirable ("larger-the-better"), the S/N ratio is computed using the following formula:

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

Conversely, for a characteristic where a smaller value is preferable ("smaller-the-better"), the formula is:

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

where:

n = the number of experimental replications (trials),
yi = the measured value of the response for the i-th replication.

The calculated S/N ratios for the experimental data, processed using Minitab 17 software, are presented in Table 5.

Table 3. Results of S/N Ratio for Porosity and Compressive Strength

No. Exp.	Parameters				Porosity (%)	Compressive strength (MPa)	S/N Ratio (dB) Porosity	S/N Ratio (dB) Compressive Strength
	Cement (g)	sand (g)	The Green Shell Powder (g)	The Coconut Fiber Powder (g)				
1	643.21	2289.60	0.000	0.000	8	11.28	-18.0618	21.0462
2	643.21	1831.68	228.961	228.960	9	10.06	-19.0849	20.0520
3	643.21	1373.76	457.922	457.921	9.71	8.84	-19.7444	18.9290
4	643.21	915.84	686.883	686.881	10	8.72	-20.0000	18.8103
5	643.22	2289.60	228.961	457.921	9.59	8.72	-19.6364	18.8103
6	643.22	1831.68	0.000	686.881	9.59	8.68	-19.6364	18.7704
7	643.22	1373.76	686.883	0.000	8.18	8.76	-18.2551	18.8501
8	643.22	915.84	457.922	228.960	9	9.21	-19.0849	19.2852
9	643.23	2289.60	457.922	686.881	9.88	8.72	-19.8951	18.8103
10	643.23	1831.68	686.883	457.921	9.41	8.8	-19.4718	18.8897
11	643.23	1373.76	0.000	228.960	9.18	9.55	-19.2569	19.6001
12	643.23	915.84	228.961	0.000	8.06	12.5	-18.1267	21.9382
13	643.24	2289.60	686.883	228.960	8.24	9.39	-18.3185	19.4533
14	643.24	1831.68	457.922	0.000	8.18	9.15	-18.2551	19.2284
15	643.24	1373.76	228.961	686.881	9.76	8.72	-19.7890	18.8103
16	643.24	915.84	0.000	457.921	9.82	8.5	-19.8422	18.5884

Analysis Of Paving Block Parameters On Porosity

1. Analysis of the Influence of Paving Block Parameters on Porosity

Main Effects Plot After obtaining the S/N ratios, a main effects plot was used to display the change in the mean S/N ratio for each factor level. This plot allows for the identification of the key parameters that have the most significant influence on the porosity of the paving blocks, as illustrated in the following figure.

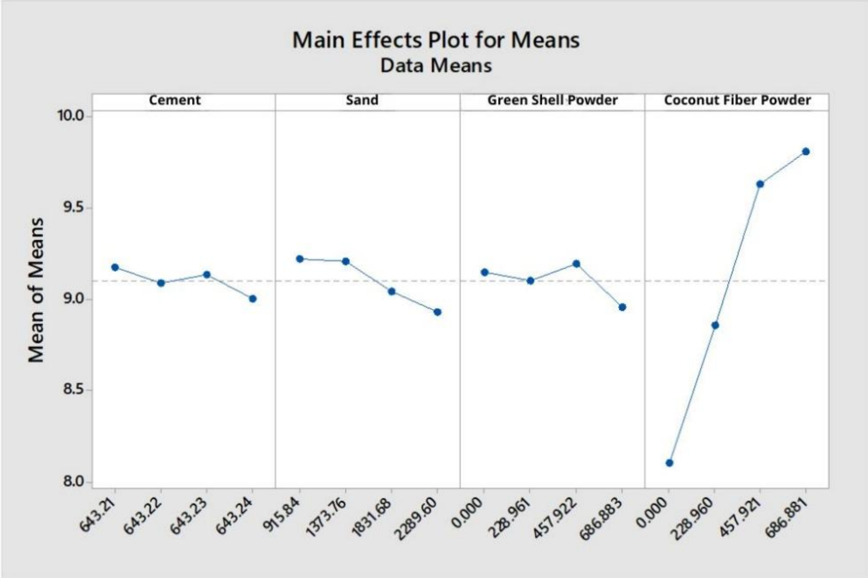

Figure 3. Main Effects Plot for Parameters on Porosity

Based on the main effects plot presented in Figure 3, the analysis of the S/N ratios indicates that coconut coir powder is the most influential factor affecting the porosity of the paving blocks. This factor demonstrates the steepest slope and the largest change in the mean S/N ratio across its levels, signifying its dominant role in controlling porosity. The sand factor exhibits a moderate influence on the response, as indicated by a smaller but still significant change in the S/N ratio values. In contrast, the parameters of cement and shell powder show relatively flat slopes in the main effects plot. This indicates that their influence on the variation of porosity is minimal or negligible within the ranges tested in this experiment.

2. Selection of Optimum Parameters from Each Level to Minimize Porosity

The optimal level for each parameter was selected based on the highest Signal-to-Noise (S/N) ratio value obtained from the response table and main effects plot analysis. According to the Taguchi method, a higher S/N ratio corresponds to minimal deviation between the desired and measured outputs, indicating greater robustness and optimal performance. The specific optimal levels for minimizing porosity are clearly identified in Figure 4 Main Effects Plot for S/N Ratio.

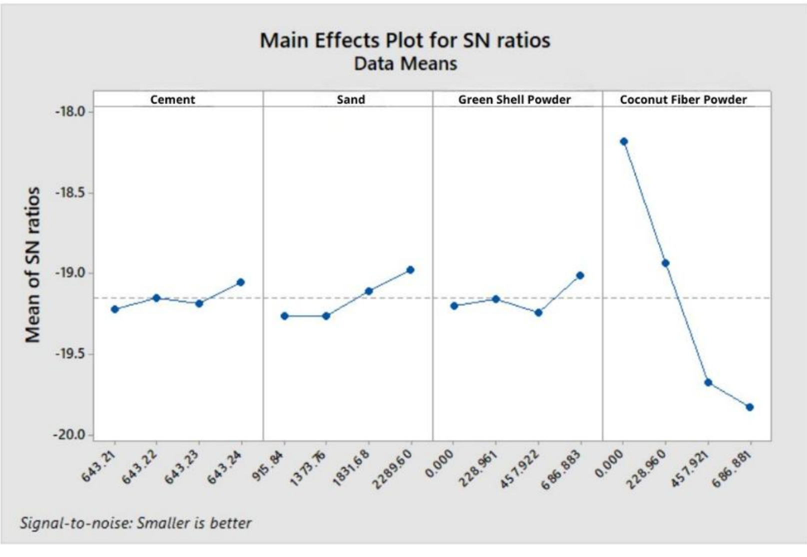

Figure 4. Main effect plot on S/N ratio

The detailed S/N ratio response values for each parameter and level are summarized in Table 6

Table 6. Response Table for Signal-to-Noise Ratios (Smaller is Better)

Levels	**Parameters Paving Block**			
	Cement (g)	**Sand (g)**	**The Green Shell Powder (g)**	**The Coconut Fiber Powder (g)**
1	-19.22	-19.26	-19.20	**-18.17**
2	-19.15	-19.26	-19.16	-18.94
3	-19.19	-19.11	-19.24	-19.67
4	**-19.05**	**-18.98**	**-19.01**	-19.83
Delta	0.17	0.29	0.23	1.66
Rank	4	2	3	1

Based on the analysis of the S/N ratio response table, the optimal level for each factor was determined by selecting the level with the highest mean S/N ratio (highlighted in bold). Cement performed optimally at Level 4 (643.24 g) with an S/N ratio of –19.05, while sand also achieved its best performance at Level 4 (915.84 g) with an S/N ratio of –18.98. Shell powder reached its optimum at Level 4 (686.883 g) with an S/N ratio of –19.01. In contrast, coconut coir powder performed best at Level 1 (0.000 g) with an S/N ratio of –18.17. The delta values, representing the range of S/N ratios, indicate that coconut coir powder (delta = 1.66) is the most dominant factor influencing paving block quality, followed by sand (0.29), shell powder (0.23), and cement (0.17). Thus, the optimal parameter combination for minimizing porosity is the use of cement, sand, and shell powder at their highest levels and coconut coir powder at its lowest level.

3. Determination of the Most Influential Parameters on Porosity Using ANOVA

Analysis of variance (ANOVA) is a statistical method used to determine the significance of experimental results by comparing the means between groups. In this study, ANOVA was employed to test the null hypothesis (H_0) that there is no relationship between a manufacturing parameter and the response (porosity). The alternative hypothesis (H_1) posits that a significant relationship exists. The significance of each parameter is assessed by comparing its p-value to a predetermined significance level ($\alpha = 0.05$). If the p-value is less than α, the null hypothesis is rejected, indicating the parameter has a statistically significant effect on porosity. This can be observed in the ANOVA table below by examining the p-value.

Table 7. ANOVA Porosity

Source	DF	Adj SS	Adj MS	F	P
Cement	3	0.06865	0.02288	0.22	0.875
Sand	3	0.23495	0.07832	0.77	0.584
The Green Shell Powder	3	0.12450	0.04150	0.41	0.761
The Coconut Fiber Powder	3	7.33665	2.44555	23.94	**0.013**
Error	3	0.30645	0.10215		
Total	15	8.07120			

The results of the analysis in Table 7 (ANOVA) indicate that among the four factors tested, only coconut coir powder has a significant effect on the porosity of the paving blocks, while the factors of cement, sand, and shell powder show no significant influence (p-value > 0.05). Therefore, controlling the composition of coconut coir powder is a critically important aspect in efforts to reduce the porosity of paving blocks.

4. Parameter Modeling of Porosity Using Regression Testing

In this study, testing was conducted using linear regression analysis in Minitab17 software. The resulting capability model was evaluated using the coefficient of determination (R-squared). The coefficient of determination value ranges from zero to one. A value close to one indicates a good fit between the dependent and independent variables. The regression model developed for porosity in this study had an R-squared value of more than 70% (0.07), approaching 1, at 0.8967 from 89.67%. The coefficients in the improved model were checked for significance using a residual plot. If the residual plot is a straight line, then the model is normally distributed and the coefficients are significant. Figure 5 shows that the residuals are close to a straight line, indicating that the model coefficients are significant.

Table 6. Results of R-squared Calculations

s	R-sq	R-sq (adj)
0.275373	89.67%	85.91%

Regression Formula:
Porositas (%) = 3160 - 4.90 Cement - 0.000227 sand - 0.000210 The Green Shell Powder + 0.002570 Coconut Fiber Powder

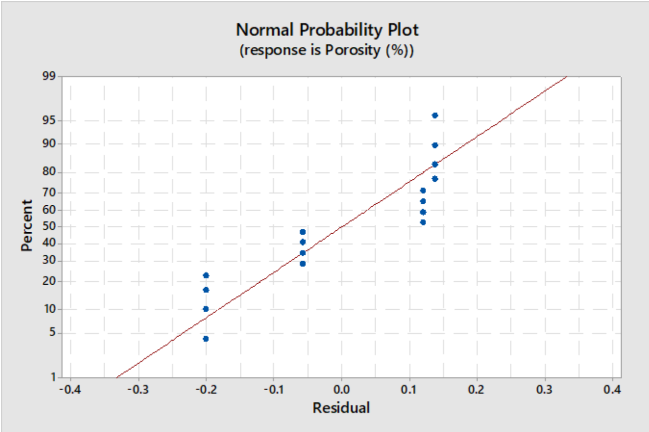

Figure 5. Normal Probability Plot (Porosity)

The Normal Probability Plot shows that the residual porosity is distributed approximately normally, so the model and statistical analysis used are feasible.

Analysis of Paving Block Parameters On Compressive Strength

1. Analysis of the Influence of Paving Block Parameters on Compressive Strength

Based on the S/N ratio results in Table 5, the main effects plot visually displays the change in mean S/N ratio across factor levels, identifying the most influential parameters on compressive strength. This plot highlights factors that significantly enhance compressive strength and determines their optimal levels for paving block production.

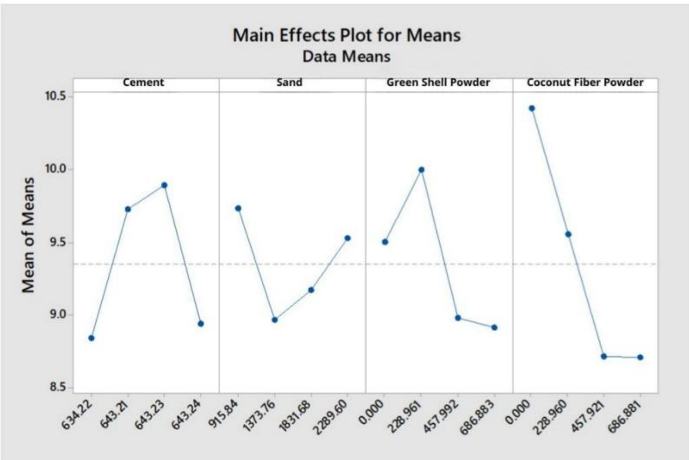

Figure 6. Main Effects Plot for Compressive Strength

2. Selection of Optimum Parameters from Each Level to Minimize Compressive Strength

The optimal level for each parameter was determined by selecting the level with the highest S/N ratio value from the response table, in accordance with the Taguchi method. A higher S/N ratio indicates minimal deviation between the desired and measured outputs, ensuring robustness. The specific optimal levels are visually confirmed in Figure 6 S/N Ratio Main Effects Plot.

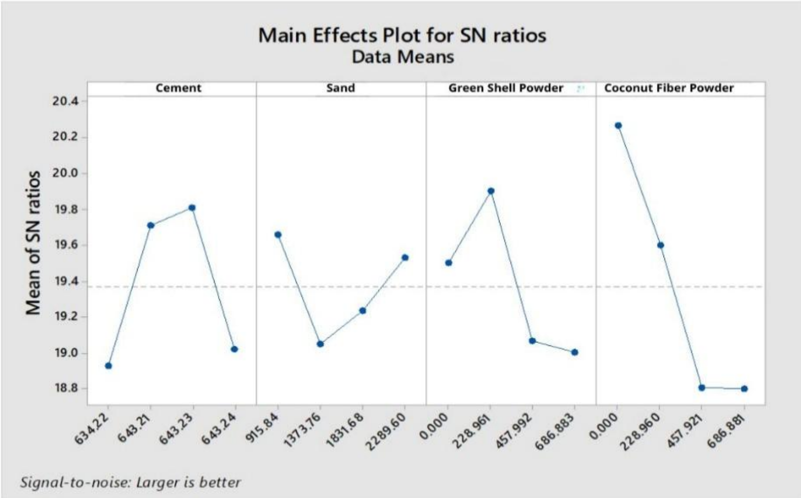

Figure 7. S/N Ratio Main Effects Plot.

The residual plot indicates that the data closely follows a normal distribution, as the points align approximately along the straight reference line. This validates the assumption of normality, ensuring the accuracy of confidence interval estimations and predictive models. Detailed S/N ratio response values for each parameter are provided in Table 8.

Table 8. Response Table for Signal-to-Noise Ratios (*larger-the-better*)

Levels	Parameter Paving Block			
	Cement (g)	Sand (g)	The Green Shell Powder (g)	The Coconut Fiber Powder (g)
1	19.71	**19.66**	19.50	**20.27**
2	18.9	19.05	**19.90**	19.60
3	**19.81**	19.24	19.06	18.80
4	19.02	19.53	19.00	18.80
Delta	0.88	0.61	0.90	1.47
Rank	3	4	2	1

According to the analysis of the response table 8, the optimal levels for each parameter, corresponding to the highest mean S/N ratios, were identified. Cement achieved optimal performance at Level 3 (643.23 g, S/N ratio: 19.81), while sand performed best at Level 1 (2289.60 g, S/N ratio: 19.66). Shell powder yielded the highest S/N ratio at Level 2 (228.96 g, S/N ratio: 19.90), and coconut coir powder exhibited optimal results at Level 1 (0.000 g, S/N ratio: 20.27). The delta values revealed that coconut coir powder (delta: 1.47) was the most dominant factor influencing paving block quality, followed by shell powder (0.90), cement (0.88), and sand (0.61). Thus, the optimal parameter combination to maximize compressive strength is cement at Level 3, sand at Level 1, shell powder at Level 2, and coconut coir powder at Level 1.

3. Determination of the Most Influential Parameters on Compressive Strength Using ANOVA

Following the same methodology as previous measurements, the Analysis of Variance

(ANOVA) table was obtained as presented below. This table statistically validates the significance of each factor's influence on the response variable, with p-values indicating whether observed effects are statistically significant ($p < 0.05$) or not.

Tabel 9. ANOVA Compressive Strength

Source	DF	Adj SS	Adj MS	F	P
Cement	3	3.442	1.1475	1.75	0.328
Sand	3	1.422	0.4742	0.72	0.601
The Green Shell Powder	3	3.079	1.0263	1.57	0.360
The Coconut Fiber Powder	3	8.016	2.6721	4.09	**0.139**
Error	3	1.962	0.6541		
Total	15	17.922			

The ANOVA results from Table 8 indicate that none of the four factors exhibit a statistically significant influence on compressive strength, as all p-values exceed the 0.05 threshold. However, among these parameters, coconut coir powder demonstrates a p-value closest to 0.05, influence on compressive strength compared to the other factors. Thus, coconut coir powder may still be considered the most influential factor in modulating the compressive strength of paving blocks within this experimental context.

4. Parameter Modeling of Compressive Strength Using Regression Tests

In this study, testing was conducted using linear regression analysis in Minitab17 software. The regression model developed for compressive strength in this study had an R-squared value at 0.5625 from 56.25%. The coefficients in the improved model were checked for significance using a residual plot. If the residual plot is a straight line, then the model is normally distributed and the coefficients are significant. Figure 8 shows that the residuals are close to a straight line, indicating that the model coefficients are significant.

Table 6. Results of R-squared Calculation

s	R-sq	R-sq (adj)
0.844269	56.25%	40.34%

Regression Formula:
Compressive Strength (MPa) = -37.2 + 0.0750 Cement - 0.000090 Sand - 0.001212 The Green Shell Powder- 0.002610 Coconut Fiber Powder

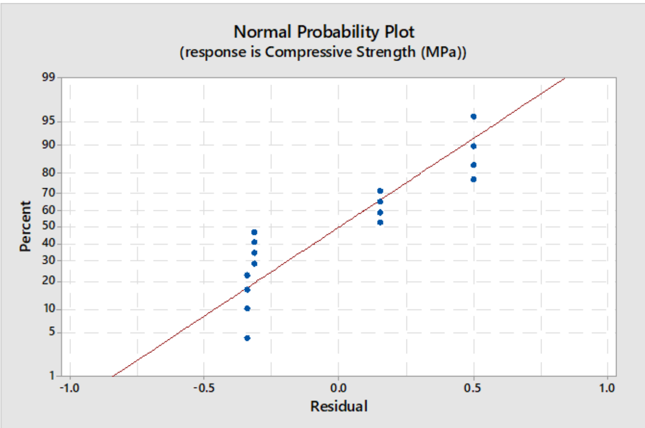

Figure 8. Normal Probability Plot (Compressive Strength)

The Normal Probability Plot shows that the residual Compressive Strength is distributed approximately normally, so the model and statistical analysis used are feasible.

CONCLUSION

Through the analysis of signal-to-noise ratios, the optimal parameter levels for minimizing porosity and maximizing compressive strength were determined. For porosity reduction (smaller-the-better), the optimal levels were cement at Level 4 (643.24 g, S/N: -19.05), sand at Level 4 (915.84 g, S/N: -18.98), shell powder at Level 4 (686.88 g, S/N: -19.01), and coconut coir powder at Level 1 (0.000 g, S/N: -18.17). For compressive strength enhancement (larger-the-better), the optimal levels were cement at Level 3 (643.23 g, S/N: 19.81), sand at Level 1 (2289.60 g, S/N: 19.66), shell powder at Level 2 (228.96 g, S/N: 19.90), and coconut coir powder at Level 1 (0.000 g, S/N: 20.27). Notably, coconut coir powder consistently achieved optimal performance at Level 1 for both responses, identifying it as the most critical factor in simultaneously improving porosity and strength characteristics of the paving blocks. This underscores its key role in optimizing the overall quality of the final product.

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