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REUSE OF SPUN PILE PRODUCTION WASTE FOR PAVING BLOCK DEVELOPMENT BY TAGUCHI METHOD

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Abstrak

[Title: Optimization of Precast Concrete Paving Block Production from Waste Concrete Using the Taguchi Method] *The production of precast spun piles generates solid and liquid waste products. The solid waste consists of stone, sand, and mud materials, while the liquid waste consists of K-600 grade concrete cement mixed with water. It is poured into a 1m3 container and solidifies within 3 hours. The production process of precast concrete piles is fast, which results in quick waste accumulation in the factory area. This research aims to transform the waste into paving blocks suitable for road construction. The Taguchi method is employed to determine the optimal strength of the paving blocks using three variables: (1) the ratio of solid to liquid waste in three levels - 70:30%, 60:40%, and 50:50%, (2) mixing time in three levels - 5, 10, and 15 minutes, and (3) curing time in three levels - 3, 7, and 14 days. The strength of the paving blocks is tested by measuring the maximum compressive strength. The results indicated that the best combination for achieving maximum compressive strength was using (1) a 50%:50% ratio of solid to liquid waste, (2) a curing time of 14 days, and (3) a mixing time of 5 minutes, resulting in a maximum compressive strength of 125.72 Kg/cm2. It is equivalent to Grade D paving blocks that are suitable for road application.*

Keywords: *paving block; industrial waste; precast concrete; Taguchi; circular economy*

1. Introduction

Infrastructure development stimulates the growth of manufacturing industries of spun piles. Spun pile is a type of pile used in construction for buildings and bridges. Spun piles are prestressed concrete piles with a circular hollow section (Refani & Nagao, 2023). They are manufactured by centrifugally casting concrete into a cylindrical mold, which results in a denser and stronger pile (Han et al., 2023). Spun piles are known for their ability to be driven through hard strata and their high flexural strength (Refani & Nagao, 2023). They offer several advantages, including large bearing capacity and durability against corrosion (Faisal et al., 2023). Spun piles are commonly used in the construction industry, particularly in pile foundations, due to their structural integrity and load-bearing capabilities.

The manufacturing industry of spun piles produces by-products from the batching plant. A batching plant, also known as a concrete batching plant or concrete mixing plant, is a facility used to combine various ingredients such as water, cement, aggregates (sand, gravel, or crushed stone), and additives to produce concrete. The plant operates by mixing these components in specific proportions to create concrete of desired quality and consistency. Batching plants come in various sizes and configurations, ranging from small-scale portable plants to large stationary plants (Khedmatgozar Dolati & Mehrabi, 2021). Batching plants offer precise and efficient control over the mixing process, ensuring consistent and uniform concrete production.

Liquid and solid waste from the production process of spun piles are classified as hazardous industrial waste. This is due to the presence of cement and concrete waste materials, which can degrade the quality of groundwater and lead to decreased soil fertility (Hossain et al., 2020). Consequently, proper and effective management of this waste is essential. According to Indonesian governmental regulation no.74 (2001), hazardous and toxic substances are substances that, due to their nature, concentration, and/or quantity, directly or indirectly, can contaminate or damage the environment and/or pose a threat to the environment, human health, and the survival of other living organisms. Therefore, one approach to managing the by-products of spun pile production is to utilize them as valuable materials to produce other products, such as paving blocks. Paving blocks are a composition of construction materials made from a mixture of Portland cement or other hydraulic binders, water, aggregate, and may include additional additives

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without compromising the quality of the concrete (SNl 03-0691-1996). Paving blocks are commonly used for road surfaces, yards, or parking areas. In addition to being environmentally friendly due to their ability to allow water to penetrate directly into the ground through their gaps, paving blocks also come in various shapes and colors. They can withstand certain loads and are easy to install, making them widely used by the community.

There is no specific information regarding the market demand for paving blocks in Indonesia. However, it's worth mentioning that the global paving materials market is expected to grow significantly, driven by factors such as increased infrastructure development, growth in the residential sector, and the rise in adoption of paving materials in the construction industry. It is likely that there is a growing demand for paving blocks in Indonesia as well, suitable for both personal and public purposes, such as for buildings, landscaping, driveways, and more. The advantages of this paving block product include its low production cost, ease of installation, and straightforward maintenance. It can be readily customized to meet the user's preferences. Another advantage of paving blocks is their environmental suitability, making them applicable in areas prone to high water levels, aiding in flood prevention by facilitating rainwater drainage. In essence, paving blocks can be utilized in all weather conditions and geographic terrains.

Several studies have been conducted to develop products that can be derived from construction and industrial waste. These studies aim to find innovative ways to utilize and recycle the waste generated by the construction industry. By exploring different methods and techniques, researchers are working towards creating sustainable solutions that can not only reduce waste but also contribute to the development of new products. These initiatives are crucial in promoting a circular economy and reducing the environmental impact of the construction sector. Alqarni et. al (2022) investigated the use of different recycled construction and industrial waste coarse aggregates to create a solid performance with concrete. Six types of coarse aggregates were examined, including manufactured limestone, quartzite, natural scoria, by-product industrial waste aggregate, and two sources of recycled concrete aggregates. These aggregates had varying densities ranging from 860 to 2300 kg/m3 and exhibited different strength properties. The research revealed that the density of coarse aggregate had a significant impact on the mechanical properties of concrete. Additionally, it was observed that the water absorption percentage was higher in concrete made from aggregates with greater absorption capacity.

Anggraini et al. (2019) developed paving blocks from fly ash. They employed the Taguchi method in their experimental design to obtain the compressive strength of fly ash-based paving blocks. The results of this research show that the most optimal composition for making paving blocks is a paving block sample with a curing time of 28 days, with a composition containing 7.5% fly ash, 30% cement and 60% aggregate. The effect of adding fly ash in making paving blocks is able to increase the compressive strength of paving blocks after 28 days with a compressive strength of 402.722 kg/cm. Similar research was also conducted by Ganesh et al. (2023) who developed paving blocks using additional materials derived from industrial waste. They develop geopolymer concrete which is economically friendly and sustainable paver blocks for society through mitigation of environmental strains on the ecosystem. This study employed random forest (RF) algorithm for the prediction of compressive strength of geopolymer concrete specimens for the variable parameters such as molarity of alkaline solution, Fly ash/GGBS ratio and partial replacement of river sand with iron slag.

Awolusi et al. (2021) investigated the impact of calcined clay and sawdust powder used as substitutes for cement, along with two types of chemical additives, on the strength, abrasion resistance, and slip resistance of concrete for pavement and flooring applications. The study was prompted by the increasing promotion of supplementary cementitious materials (SCMs) for use as cement replacements in concrete pavement. However, the effects on strength, abrasion resistance, and slip resistance were not adequately considered. Calcined clay was found to be a preferable substitute for a portion of cement in concrete pavement due to its higher flexural strength, slip resistance, and similar abrasion resistance compared to sawdust powder. On the other hand, sawdust powder was preferred for flooring applications due to its lower water absorption and higher compressive strength. The researchers employed the Taguchi experimental design in this study, and the experimental results indicated that the optimal percentage of calcined clay was 5%, while the optimal percentage for crystal-based additives was 1%.

Wang et al. (2023) explored the characteristics of concrete paving blocks, such as compressive strength, tensile splitting strength, water absorption, slip resistance, and abrasion resistance, through the substitution of natural aggregates with recycled concrete coarse aggregate (RCCA), crushed glass (CG), recycled concrete fine aggregate (RCFA), and ground granulated blast furnace slag (GGBS). Utilizing orthogonal experimental designs, the researchers conducted microstructure analyses to uncover the underlying mechanisms. The findings reveal that the inclusion of RCCA significantly reduced the tensile splitting strength, water absorption, and abrasion resistance of blocks incorporating multiple recycled materials, while CG had minimal impact on the tested properties. RCFA negatively affected all five blocks' properties, particularly demonstrating a significant detrimental effect on tensile splitting strength and water absorption. GGBS, at an optimal replacement level, exhibited the ability to enhance compressive strength, tensile splitting strength, and water absorption properties.

Olofinnade et al. (2021) investigates the utilization of steel industry waste, namely crushed waste furnace steel slag as a substitute for natural sand in the production of concrete block paving units for application as a pedestrian and non-traffic material. In this study, a total of 144 paver samples were fabricated, incorporating varying proportions of sand replacement materials, namely 0%, 20%, 40%, 60%, 80%, and 100% by weight of sand, using a mix ratio of 1:1.5:3 (cement: sand: granite) and a constant water-to-cement ratio of 0.5. The research results reveal a significant increase of 15% in compressive strength, notably observed in samples subjected to a 28-day curing period with a 40% sand replacement. Furthermore, a 10% enhancement in tensile strength is achieved in samples cured for 28 days with a 20% sand replacement. These improvements contrast with the gradual strength decline observed in control samples as the percentage of replacement material increases. The findings suggest the feasibility of utilizing waste furnace slag for paver production, thus contributing to environmentally friendly and sustainable road infrastructure.

In contrast to studies primarily concentrating on mechanical strength, Imran et al. (2020) pioneered the development of Paving Blocks using waste materials, with the aim of serving as a heat insulator for buildings. Their investigation delves into the practical application of paving blocks to alleviate heat-related issues. Employing quantitative approaches, including field surveys, data analysis, and laboratory experiments involving natural and waste materials, the study demonstrates that incorporating landscape hard materials, like paving blocks, contributes significantly to heat reduction. The research focuses on optimizing the composition of mixed materials in paving block manufacturing, resulting in the creation of two distinct forms: rectangular and hexagonal blocks. The utilization of paving blocks, formulated with a combination of fundamental components (cement, sand, and water), natural elements (grass and fibers), and recycled materials (sawdust and styrofoam), proves to be an effective strategy for lowering ambient temperatures.

Based on the previous studies, it is evident that industrial waste still holds the potential for reuse in the creation of new products. Furthermore, substituting previous materials with those derived from industrial waste has the capacity to enhance the technical specifications of the developed products. In our case, the manufacturing company of the spun piles PT Hakaaston, is situated in Bojonegara – Indonesia, produces by-products both solid and liquid wastes. The solid waste generated from the leftover washings in the batching plant consists of sand, stone, and mud. The liquid waste consists of high-quality concrete cement water (k-600) released from the spun pile mold during the production process and poured into a 1 m^3-sized container. This liquid waste solidifies within 3 hours due to the presence of cement water. Currently, there is no precise information regarding the amount of solid and liquid waste produced per spun pile production. However, these waste piles disrupt the production process area and can hinder the operational efficiency of the plant if not properly managed. The company faces difficulties in the transfer and finding a suitable storage location for the waste. Additionally, the current waste disposal process incurs significant expenses. Therefore, it is necessary to implement an effective waste treatment process to address these issues.

The motivation behind this research is to harness both liquid and solid waste generated from spun pile production at PT. Haakaston. The development of paving blocks from industrial waste is expected to meet the standards set by SNI 03-0691 (1996). These standards categorize paving block types based on their compressive strength. Type A exhibits compressive strength reaching up to 400 kg/cm^2 with a maximum water absorption capacity of 3%. This type, known for its high strength, is utilized for road applications. Type B, with a strength of up to 200 kg/cm2 and a maximum water absorption of 6%, is commonly used for parking areas. Type C, with a strength of up to 150 kg/cm^2, is applied for pedestrian walkways. Lastly, Type D boasts a strength of up to 100 kg/cm^2 and is typically employed as ground cover in city parks and residential yards.

The specific objective of this research is to evaluate the compressive mechanical properties of various composition variations and treatments in aggregate mixtures derived from solid and liquid waste from spun pile production. The Taguchi method is employed in this experiment, and the results will be adjusted to meet the quality criteria for paving block types in accordance with the SNI 03-0691 standard.

2. Method

The research was conducted in sequential stages, as illustrated in **Figure 1**.

Materials

The literature review aimed to acquire comprehensive knowledge about the manufacturing process and standards associated with paving blocks. During the on-site observations, two types of byproducts from spun piles production were identified at the factory. These byproduct materials encompassed solid waste components, including sand, stone, and mud, as well as liquid waste comprising concrete cement water, as illustrated in **Figure 2**. As these materials were obtained directly from the spun piles production process, they were utilized in their raw form without undergoing any separation. To further understand the composition of the materials and establish best practices for conducting experiments, expert interviews were conducted. This approach allowed us to gather insights from knowledgeable individuals in the field, ensuring a comprehensive understanding of the materials and facilitating the proper execution of the experiments.

Design of Experiment

The experiment was conducted using the Taguchi method, chosen for its efficacy in improving and optimizing the performance of a specific system or process (Ikeagwuani et al., 2020). This approach proves particularly advantageous when multiple factors or variables influence the outcome. The primary objective is to identify the most favorable combination of these factors for efficient and effective results. Concrete experts in the field provided input, recommending the use of an orthogonal array for this experiment with

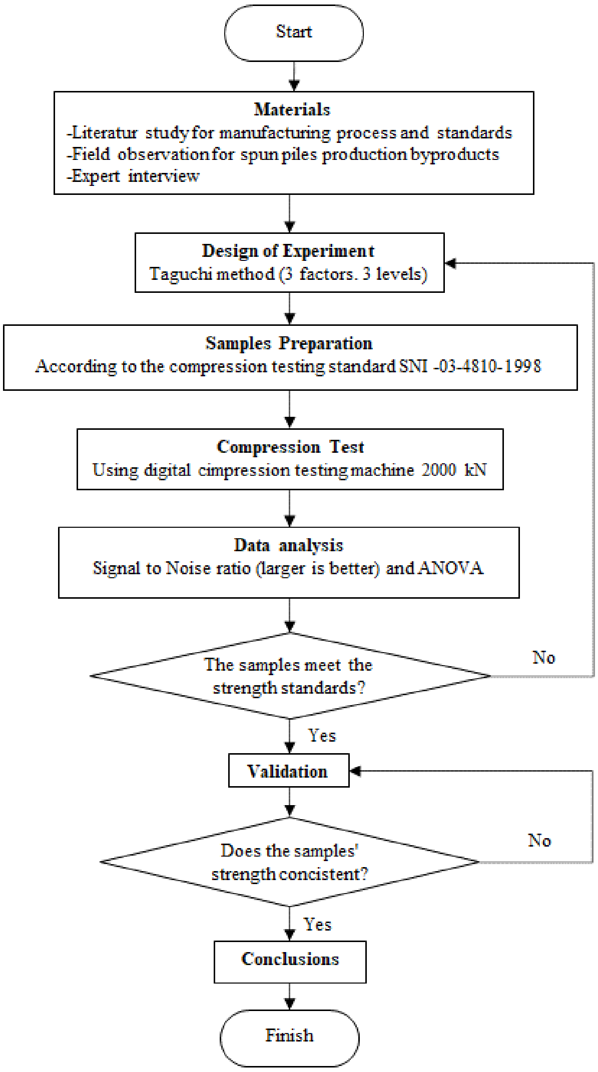

Figure 1. The Research Flowchart

Figure 2. Liquid Waste Is Poured into Mold Boxes (a), Solidified Liquid Waste (b), And A Stack of Solid Waste (c) As A By-Product from The Spun Pile Manufacturing Process

three factors, each having three levels of variation. These factors are as follows:

1. The experiment considered different curing times, specifically 3 days, 7 days, and 14 days. These timeframes were selected to align with the established guidelines provided by the SNI 2493:2011 standard, which offers recommendations for curing times in the context of the study. The choice of these specific durations allows for a comprehensive evaluation of how the curing process impacts the properties of the paving

Table 1. Factors And Levels of The Study

Factor		Level		
		1	2	3
1.	Solid: Liquid (%)	70:30	60:40	50:50
2.	Mixing time (minutes)	5	10	15
3.	Curing time (day)	3	7	14

Table 2. Experiment Setting

Run order	Solid: Liquid Composition (%)	CT (day)	MT (min.)	Code
1	70:30	3	5	A1
2	70:30	7	10	A2
3	70:30	14	15	A3
4	60:40	3	15	B1
5	60:40	7	5	B2
6	60:40	14	10	B3
7	50:50	3	10	C1
8	50:50	7	15	C2
9	50:50	14	5	C3

CT= curing time; MT= mixing time

blocks, ensuring a thorough examination of their performance over varying periods.

2. The composition ratio between solid and liquid waste (70:30%, 60:40%, and 50:50%). This ratio was determined after conducting a slump test, which revealed a slump greater than 5 cm in the 40:60% solid-to-liquid waste composition. Therefore, the maximum limit was set at a 50:50% mixture. Additionally, if the solid waste material exceeds 70%, the concrete mixture becomes brittle due to the insufficient binding agent, which is the cement-water from the liquid waste. Moreover, since solid waste is a recycled material, its strength is diminished. To prevent excessive fluidity in the paving block molds during production, a maximum slump of 5 cm was employed. This precaution is advantageous, especially if this innovative paving block meets the relevant quality standards in the future.
3. The mixing time, a crucial parameter in the concrete production process, was varied at three distinct times: 5, 10, and 15 minutes. This deliberate selection aimed to thoroughly investigate how the homogeneity of the concrete mixture is affected by different mixing times. The evaluation of compressive strength differences under these varied conditions provides valuable insights into the optimal mixing duration for achieving desired concrete properties. For further details on the specific factors and their experimental levels are presented in **Table 1**.

This study employed the Taguchi L9 array design, which entails conducting the experiment 9 times. In each trial, replication will be performed 3 times, resulting in a total of 27 experiments, as illustrated in **Table 2**.

Sample Preparation

The preparation of the test samples refers to standard SNI 03-4810-1998. The stages in the process of making test samples are as follows.

1. Mixing concrete aggregate with a composition that has been determined according to **Table 2**.
2. Conducting slump tests to ensure the workability of the aggregate used for paving block production. The slump test value must adhere to the requirement of being <5 cm to ensure ease in the paving block molding process and expedite the drying of the paving block products. The slump test is conducted in accordance with SNI 1972-2008 standards.
3. Pouring the mixture into the test sample mold to produce test samples with a diameter of 15 cm and a height of 30 cm, followed by a 24-hour resting period within the mold. After 24 hours, a unique code is assigned to each test sample to prevent any mix-up with other samples.
4. Curing is carried out in accordance with the specified duration for each sample. Following the curing period, a capping process is necessary. This procedure is performed to achieve a flat surface on the test specimen, ensuring that the compressive load from the compression testing apparatus is applied accurately.

Compression Test

The evaluation of compressive strength involves subjecting the cylindrical samples, previously prepared for testing, to a compression strength testing machine with a capacity of 2000 kN. The results generated by the machine are initially expressed in kN units. To facilitate a more practical interpretation, these values should be converted to Kg/cm2 units.

Data Analysis

The Signal-to-Noise (S/N) ratio was expressed as a logarithmic function of the target variable within the Taguchi framework and was employed in optimization studies (Anwar et al., 2022). A superior signal-to-noise ratio corresponds to a greater achievement of the objective function. In all the experiments, the objective function aimed for maximization, and it was equivalent to the signal-to-

Figure 3. Conducting A Slump Test

Table 3. Results of The Slump Test

Run	Sample	Slump Test (cm)			Average
		I	II	III	
1	A1	3.0	3.5	3.0	3.2
2	A2	3.5	3.0	3.5	3.3
3	A3	3.0	3.0	3.5	3.2
4	B1	4.0	3.5	4.0	3.8
5	B2	3.5	4.0	4.5	4.0
6	B3	4.0	4.0	4.0	4.0
7	C1	4.5	4.5	5.0	4.7
8	C2	5.0	4.5	5.0	4.8
9	C3	5.0	4.5	5.0	4.8

noise ratio. Equation (1) provides the formula for calculating the S/N ratio.

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

Analysis of Variance (ANOVA) was conducted on the compressive test data of the samples. ANOVA serves the purpose of determining the extent of influence of control factors on a process (Alam et al., 2020). The magnitude of this effect is determined by comparing the sum of squares of a control factor to the total sum of squares of all control factors. To calculate the sum of squares, you can employ formula (2).

$$SS = \sum_{i=1}^{n}(R_i - R)^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

were,
n = number of levels of each control
Ri = value of S/N ratio at the n-level
R = average value S/N ratio of a control factor

Validation

Validation of study results is a process used to verify the reliability, accuracy, and generalizability of the findings obtained through research. It involves conducting additional tests, experiments, or analyses to ensure that the results are consistent, repeatable, and applicable to a broader context. In this case, the validation of experimental results conducted in the development of paving block material from waste produced by spun piles involves performing a compression test on samples that exhibit the best compression test results.

3. Results and Discussions

Sample Preparation

The slump test is a method used to determine both the consistency and the quality level of a concrete mixture (Pereira & Maciel, 2021). In practical terms, the function of the slump test is to measure the workability of concrete. A slump test was conducted on each aggregate composition to assess the workability of each composition. The shape of the slump test mold can be observed in

Figure 3.

The slump test value must be <5 cm to ensure that the aggregate composition can be processed in the production of paving blocks. According to SNI 1972 - 2008, concrete slump refers to the reduction in the height of the center of the upper surface of the concrete immediately measured after lifting the slump test mold. The results of the slump test are presented in **Table 3**.

Table 3 illustrates that all tested aggregate compositions have values <5 cm, indicating that all these compositions are suitable for use as materials in paving block production. In other words, a slump test value approaching 0 indicates that the aggregate composition is improving (Solouki et al., 2022). Furthermore, it can be observed that as the liquid part in the aggregate composition increases, the slump test values also increase, specifically in samples C1-3, which are greater than B1-3 and A1-3. The lowest slump test values were achieved by samples A1 and A3, measuring at 3.2 cm. Conversely, the highest slump test values were attained by samples C2 and C3. The overall average slump test value, indicating the workability of the concrete mix, stands at 3.98 cm. This suggests that the composition of all samples allows for further processing in producing compressive strength test samples. Moreover, this consistency across samples indicates that the entire composition meets the manufacturability criteria required for paving block production, ensuring uniformity and quality in the manufacturing process.

There were 27 samples prepared for the compression strength test. After the curing process was carried out according to the specified time, the cylinders were initially dried for 2 hours. Before conducting the compressive strength test, it is necessary to perform the capping process. This procedure is undertaken to ensure the evenness of the test specimen's surface, thereby allowing for the maximum application of compressive force by the compression strength apparatus. Subsequently, the measurement of the test sample's weight was conducted as exhibited in **Figure 3**. This measurement is necessary as supporting data to establish a comparison of the weight between different samples. Furthermore, **Table 4** shows the results of the test sample weight measurements obtained by weighing.

The results of weighing the test samples can be observed in **Table 4**. The computation of the average weight of the compressive strength test samples, which were produced, reveals a close resemblance in weights across all samples, averaging around 12 kg. Among the samples, the lowest weight is observed in sample B3, with a recorded weight of 12,048 grams. In contrast, the highest weight is attributed to sample A2, with a total weight of 12,479 grams. This consistency in weights

Table 4. Weighing of The Sample Test

Sample	Weight (g)			Average
	I	II	III	
A1	12,351	12,251	12,515	12,372
A2	12,430	12,662	12,346	12,479
A3	12,560	12,432	12,113	12,368
B1	12,256	12,305	12,423	12,328
B2	12,751	12,561	12,122	12,478
B3	12,059	12,050	12,035	12,048
C1	12,146	12,351	12,322	12,273
C2	12,159	12,452	12,521	12,377
C3	12,024	12,505	12,123	12,217

Figure 1. Capping of The Compression Sample Test (a) And Weighing (b)

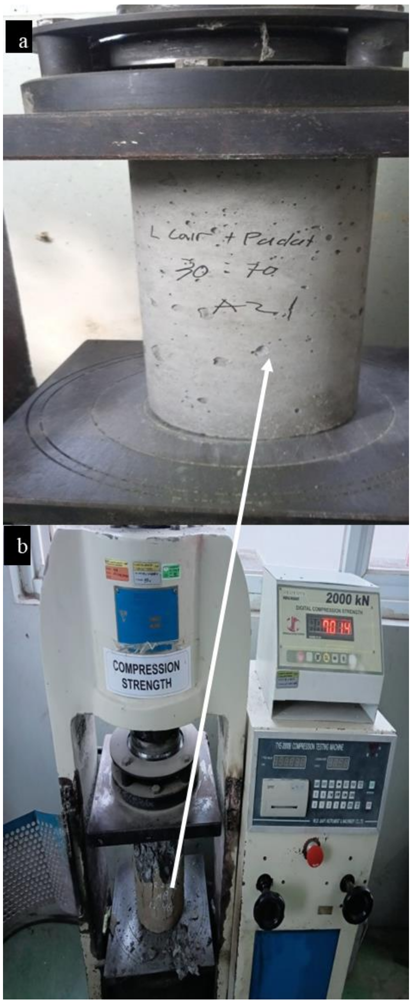

Figure 2. Compression Test

Table 5. Results of The Compression Test

Sample	Compression Test (Kg/cm^2)			S/N	$\bar{x}$	SD
	I	II	III			
A1	38.01	39.89	42.53	32.05	40.14	2.27
A2	72.14	68.52	66.58	36.77	69.08	2.82
A3	121.96	125.99	128.63	41.97	125.53	3.36
B1	57.26	48.79	52.68	34.41	52.91	4.24
B2	87.29	85.76	83.60	38.64	85.55	1.85
B3	66.44	57.89	64.77	35.94	63.03	4.53
C1	72.14	67.97	66.51	36.75	68.87	2.92
C2	47.95	41.84	47.46	33.16	45.75	3.40
C3	97.64	104.73	101.11	40.09	101.16	3.54

ensures uniformity in the manufacturing process and provides a baseline for further analysis of compressive strength.

Compression Test

The compressive strength testing of the previously prepared cylindrical samples was conducted using a compression strength machine as exhibited in **Figure 5**. The test samples, in the form of cylinders with a diameter of 15 cm and a height of 30 cm, were positioned on the compressive strength testing machine, as depicted in **Figure 5a**. Meanwhile, the appearance of the compressive strength testing machine, with a maximum compressive strength of 2000 kN, is visible in **Figure 5b**. In the image, one can observe the samples that have been crushed after undergoing testing.

The results of the compression test along with the S/N Ratio calculation can be seen in

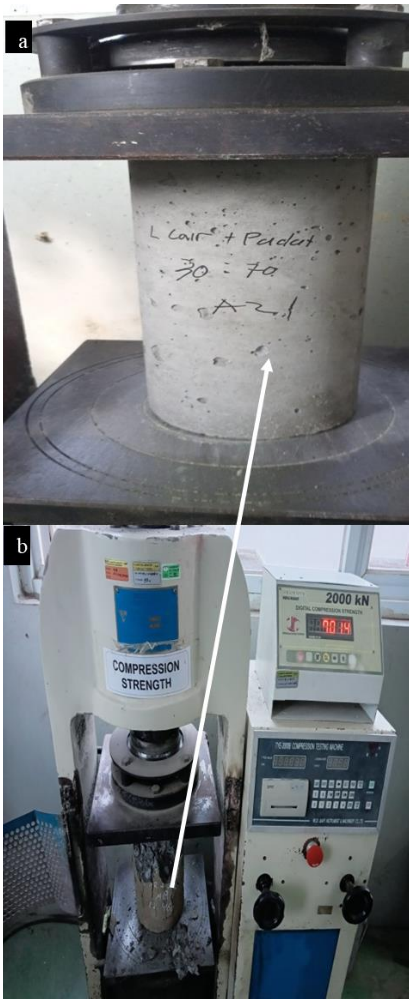

Figure 5. Compression Test

Table 5. The S/N Ratio was calculated to determine the most optimal factor and level for the composition in relation to compressive strength, using the "larger is better" criterion. This selection is grounded in the theory that the larger the resulting value, the better the outcome.

S/N Ratio

The Taguchi optimization procedure was applied to pursue the desired experimental response for each performance criterion individually. Utilizing the

Table 6. Response for S/N Ratios

Larger is better			
Level	**Mixing Time**	**Composition**	**Curing Time**
1	36.93	39.33	33.72
2	36.33	36.19	37.09
3	36.66	34.40	39.12
Delta	0.60	4.93	5.40
Rank	3	2	1

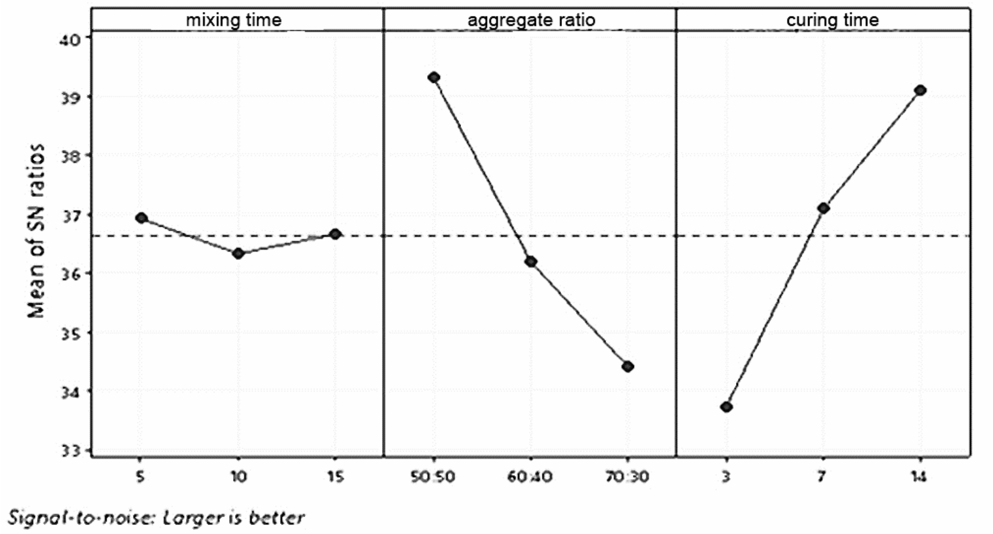

Figure 3. Main Effects Plot for S/N Ratios

Table 7. Results of The ANOVA Test

Source	DF	Seq SS	Contribution (%)	Adj SS	Adj MS	F-Value	P-Value
Mixing time	2	185.6	3.05	185.6	92.82	1.37	0.421
Composition	2	2856.1	47.25	2866.1	1433.03	21.22	0.045
Curing time	2	2877.9	47.45	2877.9	1438.96	21.31	0.045
Error	2	135.0	2.23	135.0	67.52		
Total	8	6064.7	100				

S= 8.21723 R-Sq= 97.77% R-Sq (Adj.)= 91.09%

signal-to-noise ratios (S/N), the optimal mixture proportions were determined for the compressive strength performance criteria. The response effect calculation for the S/N Ratio for the compressive strength outcome factor was conducted using Minitab 20 software. The results of the S/N Ratio response calculation are presented in **Table 6**.

The maximum level for each factor corresponds to the highest S/N Ratio response value. Based on **Table 6**, the highest value for mixing time is at Level 1, with a value of 36.93, while for the solid waste: liquid waste aggregate composition, it is at Level 1, with a value of 39.33, and for curing time, it is at Level 3, with a value of 39.12. Subsequently, there is a plot of the main effects for the S/N Ratio, as depicted in **Figure 5**.

Based on **Figure 6**, the highest point was selected, which signifies that the higher the signal value, the lower the noise. Therefore, the highest point corresponds to Level 1 for mixing time, which is 5 minutes, Level 1 for the solid waste:liquid waste aggregate ratio, which is a 50%:50% ratio, and Level 3 for a curing time of 14 days.

ANOVA Test

An ANOVA test was conducted to ascertain the influence of the control factors on the compressive strength test results. The results of the ANOVA test can be observed in **Table 7**. **Table 7** demonstrates that the highest F-Value is associated with curing time, with a value of 21.31, indicating the most significant influence on the compressive strength test. Following this, the second highest is the solid waste: liquid waste composition ratio, with a value of 21.22, and the third is mixing time, with a value of 1.37. In this research, the analysis of P-values employed a significance level of $P<0.05$, meaning that if the P-value is less than 0.05, the factor has a significant effect. Conversely, if the P-value is greater than 0.05, the factor does not have a significant effect. In the figure above, it can be concluded that the value of 0.045 for the solid waste:liquid waste composition ratio indicates a significant effect. Likewise, the value of 0.045 for curing time significantly affects the compression strength. While the value of 0.421 for mixing time indicates an insignificant effect ($P>0.05$).

In this experiment, the R-Square value of 97.77%, which indicates the goodness-of-fit or the

Table 8. Validation of The Sample C3

Sampel	Compression Test (Kg/cm^2)			$\bar{x}$	SD
	I	II	III		
C3	125.3	124.53	127.31	125.72	1.44

proportion of the total variation in the data that is explained by the factors investigated. Specifically, it means that approximately 97.77% of the variability in the compressive strength test results of the samples can be attributed to the factors studied, such as the solid waste:liquid waste composition ratio, curing time, and mixing time.

This high R-Square value suggests that the factors tested have a substantial and significant impact on the compressive strength of the samples. In other words, the experimental factors have been effective in explaining and accounting for the observed variations in the results. Only about 2.23% of the variability remains unexplained, which could be due to factors or variables not included in this study, measurement errors, or other sources of variability that were not accounted for. Overall, a high R-Square value (97.77%) is a positive indicator of the reliability and relevance of the experimental findings.

Validation

To validate the findings, the samples that exhibited the most favorable test results (C3) were subjected to validation testing. The composition of solid waste to liquid waste in these samples was maintained at a ratio of 50%:50%, with a curing time of 14 days and a mixing time of 5 minutes. The validation process involved repeating compression tests on the selected samples, and this was done three times to ensure consistency and reliability. The compressive strength test results for these samples are detailed in **Table 6.** Response for S/N Ratios

Larger is better			
Level	**Mixing Time**	**Composition**	**Curing Time**
1	36.93	39.33	33.72
2	36.33	36.19	37.09
3	36.66	34.40	39.12
Delta	0.60	4.93	5.40
Rank	3	2	1

, providing a comprehensive overview of their performance and confirming the robustness of the experimental outcomes.

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presents the compressive strength results for sample C3, yielding an average compressive strength value of 125.72 Kg/cm2. This value is slightly higher than the previous experimental result, which was 101.16 Kg/cm2, indicating a difference of 24.56 Kg/cm2 or 24%. This variance is believed to have occurred due to the non-uniform composition of solids. Since the materials used are entirely from the waste generated in the spun pile production process, it was not feasible to separate them before the experiment to maintain composition accuracy. Nevertheless, with the aggregate composition in sample C3 generally surpassing the target quality category for Type D paving blocks (100 Kg/cm2).

Moreover, the practical implications of utilizing sample C3 as ground cover in gardens and residential yards should be emphasized. This application not only aligns with the quality standards for paving blocks but also presents a sustainable and aesthetically pleasing solution for landscaping. The results from previous studies utilizing waste to produce paving blocks indicate similar outcomes, primarily suitable for pedestrian applications or similar purposes. The study by Ollofinade et al. (2021) successfully developed interlocking concrete paving blocks incorporating furnace slag, meeting the specified standards for strength in interlocking paving block units. These blocks are suitable for non-traffic applications like pedestrian walkways, landscaping, or very light traffic driveways around buildings and parking areas. Additionally, Solouki et al. (2022) demonstrated that concrete paving blocks produced from waste materials, including gravel, sand, and silt, exhibit promising properties for use in pedestrian walkways. Furthermore, Awolusi et al. (2021) presented results indicating that paving blocks made from sawdust ash can serve as a partial substitution for cement in non-pavement concrete applications such as flooring and bricks.

4. Conclusions

This research has successfully investigated the compressive strength of paving block materials derived from the waste produced in spun pile production. The compressive strength test results of the samples yielded the best compressive strength value of 101.16 Kg/cm2 (sample C3), and its strength has been validated, allowing it to fall within the paving block product Type D category. This category is suitable for applications in city parks and residential yards.

Hence, sample C3, with a solid waste: liquid waste composition ratio of 50:50%, produced an optimal concrete mix due to the high-quality K-600 cement-water mixture. A higher proportion of liquid waste can significantly increase compressive strength while still adhering to the maximum slump value of 5 cm, ensuring ease of processing in paving block molds. Furthermore, a curing time of 14 days has a substantial impact on compressive strength because the concrete samples undergo maximum chemical reactions during this 14-day curing period.

The results presented encouraging outcomes for the creation of concrete paving blocks utilizing byproducts from spun piles production. Nevertheless, enhancements are necessary to verify the practical application of this experimental material in paving construction. Future studies are necessary to explore Conduct comprehensive performance tests under various conditions, including real-world scenarios, to validate the material's suitability for different paving applications.

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