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The Effect of Curing Temperature on the Mechanical Characteristics of Paving Blocks with Fly Ash and Coconut Fiber Mixture for Road Pavements

Muhammad Farras Nashir[1], Muhammad Isradi[2*], Syafiadi Rizki Abdila[3],
Agung Sumarno[4], Agus Mudo Prasetyo[5], Johan Budiman[6]
[1]Civil Engineering Student, Faculty of Engineering, Universitas Mercu Buana Jakarta, Indonesia
[2]Department of Civil Engineering, Universitas Mercu Buana Jakarta, Indonesia
[3,4,5] Research Center for Structural Strength Technology, National Research and Innovation Agency, BJ Habibie Science and Technology Center, South Tangerang, Banten, 15314, Indonesia
[6]Faculty of Engineering, Universitas Islam Syekh Yusuf Tangerang, 15118 Tangerang, Banten, Indonesia
[1]farrasnashir14@gmail.com, [2]isradi@mercubuana.ac.id, [3]syaf015@brin.go.id, [4]agun025@brin.go.id,
[5]agus108@brin.go.id, [7]joebudiman@unis.ac.id

Abstract

The increasing demand for environmentally friendly construction materials has encouraged the use of industrial and organic waste, such as fly ash and coconut fiber, as alternative additives in paving block production. This study aims to evaluate the effects of using fly ash as a partial cement replacement and coconut fiber as an additive on the mechanical strength and environmental aspects of paving blocks. The research method is experimental, based on SNI 03-0691-1996 and ASTM C109/C109M-21 standards. The mix variations consisted of 0%, 10%, 15%, and 20% fly ash, with an addition of 2% coconut fiber, using two curing methods: room temperature and water immersion. The compressive strength test results at 28 days showed that room temperature curing produced values of 11.07 MPa, 11.58 MPa, 12.85 MPa, and 12.06 MPa, respectively. Meanwhile, water immersion curing yielded 14.40 MPa, 14.89 MPa, 16.13 MPa, and 15.69 MPa. The highest flexural strength, 4.25 MPa, was achieved with a mixture of 10% fly ash and 2% coconut fiber cured by water immersion. The use of fly ash and coconut fiber not only enhances the mechanical strength of paving blocks but also contributes to reducing industrial and agricultural waste. This combination has proven effective in improving material performance while supporting sustainable development as an eco-friendly solution.

Keywords: *Fly Ash, Coconut Fiber, Paving Block, Compressive Strength, Flexural Strength, And Curing.*

1. Introduction

The significant growth of infrastructure development has driven increased demand for construction materials, including paving blocks. This material is widely used due to its advantages such as ease of installation, simple maintenance, relatively low cost, and water absorption capability, which supports groundwater conservation [1]. Paving blocks are solid precast concrete materials made from a mixture of cement, sand, water, and aggregates. Their production can be carried out manually, using a press machine, or through hydraulic techniques [2]. Applications are extensive across various pavement types, such as neighborhood roads, sidewalks, parking areas, yards, and parks [3].

Paving block production generally still relies on Portland cement as the primary binder. However, high cement consumption significantly contributes to carbon dioxide (CO_2) emissions. According to data from the Indonesian Cement Association (ASI), domestic cement demand has increased by 7.6% annually since 2017, reaching 66.35 million tons. Cement production emits more than one ton of CO_2 for every ton of cement produced, making it one of the largest contributors to carbon emissions [4]. Globally, the cement industry accounts for more than 8% of total carbon emissions, primarily due to energy consumption and the calcination process in production [5]. Therefore, alternative solutions are needed to reduce cement consumption in concrete mixtures, particularly in paving blocks [6].

One potential alternative material to partially substitute cement is fly ash, a coal combustion residue from Coal-Fired Power Plant (CFPP) rich in silica and alumina, which can act as a pozzolanic material [7]. The use of fly ash in paving block mixtures not only reduces cement demand but also supports the reduction of industrial waste that pollutes the environment [8]. In addition to environmental benefits, fly ash has been shown to improve the mechanical properties of paving blocks, particularly compressive strength and resistance to extreme environmental conditions [9], [10].

Besides fly ash, organic waste materials such as coconut fiber can also be utilized as an additive. Coconut fiber contains a high cellulose content (approximately 78.14%), which contributes to improving the mechanical properties of concrete, especially flexural strength [11]. Adding coconut fiber can enhance crack resistance and increase material flexibility, thereby extending the service life of paving blocks [12]. Coconut fiber is also abundantly available and relatively inexpensive, making it a viable sustainable additive that supports environmentally friendly practices [13].

Another factor affecting paving block quality is the curing method. Curing plays an important role in supporting cement hydration and the development of concrete strength. Room-temperature curing offers production efficiency, while water-immersion curing can maintain optimal moisture for hydration reactions. Variations in curing temperature may influence the mechanical properties of paving blocks, especially when combined with alternative materials [14].

Based on this background, the present study aims to evaluate the effect of curing temperature variations on the mechanical properties of paving blocks produced with partial cement substitution using fly ash (0%, 10%, 15%, and 20%) and the addition of 2% coconut fiber. The study is expected to produce an optimal mixture composition that meets the requirements of SNI 03-0691-1996 and supports more sustainable paving block production.

2. Research Methods

2.1 Approach, Location, and Time of Research

This study employed an experimental method, as it was conducted by applying various treatments based on references from previous research journals [15]. The research referred to SNI 03-0691-1996 for the technical specifications of paving blocks and ASTM C109/C109M-21 for the standard test method for compressive strength of hydraulic cement mortar. The experiments were carried out at the Laboratory of Universitas Mercu Buana, located on Jalan Meruya Selatan, Kembangan District, Jakarta, and at the Laboratory of Universitas Islam Syekh Yusuf, Tangerang District, Banten, during the period of May to July 2025.

2.2 Research Variables

In this study, two types of test specimens with different dimensions were used: cubes measuring 5 cm × 5 cm × 5 cm for compressive strength testing and beams measuring 21 cm × 10.5 cm × 6 cm for flexural strength testing. The mixture variations consisted of 0%, 10%, 15%, and 20% fly ash as a partial replacement for cement, along with 2% coconut fiber as an additive in each variation. The curing process was carried out under two different conditions—water immersion and room temperature—to evaluate their effects on the characteristics of the paving blocks. Compressive strength tests were conducted at 7, 14, and 28 days, while flexural strength tests were conducted at 28 days. In addition to compressive strength testing, the specimens were also tested for water absorption at 28 days. The aim of this study is to determine the optimal curing method and mixture proportions to produce paving blocks with the best mechanical quality [16], [17].

2.3 Research Samples

The number of research samples for compressive strength and flexural strength tests is shown in Table 1.

Table 1. Number of Samples for Compressive Strength and Flexural Strength Tests

No.	Sample	Compressive Strength Test			Flexural Strength Test	Total Samples
		7 Days	14 Days	28 Days	28 Days	
1.	100% Cement and 100% Sand (Control)	6	6	6	4	22
2.	10% *FA* dan 100% Sand + 2% CF	6	6	6	4	22
3.	15% FA dan 100% Sand + 2% CF	6	6	6	4	22
4.	20% *FA* dan 100% San + 2% CF	6	6	6	4	22
	Total Samples					88

Note:
FA : Fly Ash
CF : Coconut Fiber

For the compressive strength test, each mixture variation consisted of 6 samples, divided into two curing treatments: 3 samples cured at room temperature and 3 samples cured by water immersion. For the flexural strength

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test, each variation consisted of 4 samples, with 2 samples cured at room temperature and 2 samples cured by water immersion.

2.4 Mix Design Calculation

The mix design used in this study is presented in Table 2.

Table 2. Material Requirements for 6 Samples Measuring 5 × 5 × 5 cm

Sample	Mold Volume (cm^3)	Cement (gram)	Fly Ash (gram)	Sand (gram)	Water (gram)	Coconut Fiber (gram)
1.	125	100% Cement: 500	-	100% Sand: 1375	242	-
2.	125	450	10% FA: 50	100% Sand: 1375	242	10
3.	125	425	75	100% Sand: 1375	242	10
4.	125	400	100	100% Sand: 1375	242	10

2.5 Paving Block Quality Requirements

The quality requirements for paving blocks are regulated in SNI 03-0691-1996, which stipulates that paving blocks must meet the physical properties shown in Table 3.

Table 3. Paving Block Quality Requirements

Grade	Compressive Strength (MPa)		Abrasion Resistance (mm/minute)		Maximum Average Water Absorption. (%)
	Average	Min.	Average	Min.	
A	40	35	0.090	0.103	3
B	20	17.0	0.130	0.149	6
C	15	12.5	0.160	0.184	8
D	10	8.5	0.219	0.251	10

3. Results and Discussions

3.1 Testing and Preparation of Materials

The purpose of material testing is to determine whether the materials used for paving block production are suitable for use, in accordance with SNI 03-0691-1996. This stage is the initial step to determine the physical properties and quality of each component, including fine aggregate, cement, fly ash, coconut fiber, and water. The results of this testing will serve as the basis for determining material feasibility so that the produced paving blocks meet the required quality standards. The material testing for paving block production includes:

1. Fine Aggregate Testing
   The fine aggregate used is Bangka sand. Prior to the mix design process, several tests were carried out to determine the characteristics of the fine aggregate. The results of the fine aggregate testing are presented in Table 3, while the documentation during testing is shown in Figure 1.

Table 3. Summary of Fine Aggregate Testing

No.	Test	Standard	Result	Requirement	Unit	Remarks
1.	Moisture Content	SNI 03-1971-2011	11.11	3-5	%	Not Qualified
2.	Specific Gravity	SNI 1969-2008	1.94	1.6-3.3	gr/cm^3	Qualified
3.	Water Absorption	SNI 1969-2008	5.04	0.2-2.0	%	Not Qualified
4.	Silt Content	SNI 03-4142-1996	36.24	5	%	Not Qualified
5.	Bulk Density	SNI 03-4804-1998	986.87	1400-1900	kg/m^3	Not Qualified
6.	Sieve Analysis (Fineness Modulus)	SNI 03-1968-1990	3.30	2.30-3.10	-	Not Qualified

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Figure 1. Documentation of Fine Aggregate Testing

2. Cement Testing

   The cement used is PCC (Portland Composite Cement) with the Gresik Cement brand. Before conducting the mix design, several tests were carried out to determine the cement characteristics. The results of the cement testing are presented in Table 4, and the documentation during testing is shown in Figure 2.

Table 4. Summary of Cement Testing

No.	Test	Standard	Result	Requirement	Unit	Remarks
1.	Specific Gravity	SNI 03-2531-1991	3.0	3.0-3.2	gr/cm^3	Qualified
2.	Sieve Analysis (Retained on No. 200 Sieve)	SNI 15-2530-1991	34	10	%	Not Qualified

Figure 2. Documentation of Cement Testing

3. Fly Ash Testing

   The fly ash used was obtained from the Paiton Coal-Fired Power Plant (CFPP) in East Java. Prior to mix design, tests were conducted to determine the characteristics of the fly ash. The results are presented in Table 5, and documentation during testing is shown in Figure 3.

Table 5. Summary of Fly Ash Testing

No.	Test	Standard	Result	Requirement	Unit	Remarks
1.	Specific Gravity	SNI 03-2531-1991	2.5	2.2-2.6	gr/cm3	Qualified
2.	Sieve Analysis (Retained on No. 200 Sieve)	SNI 15-2530-1991	40.8	-	%	-

The chemical composition of the fly ash was determined using X-Ray Fluorescence (XRF), as shown in Table 6.

Table 6. X-Ray Fluorescence (XRF) Analysis Results

No	Compound	Content (%)
1.	Al_2O_3	24.178
2.	SiO_2	36.122
3.	SO_3	1.892
4.	CaO	15.118
5.	Fe_2O_3	11.340

Based on ASTM C618, which classifies pozzolans into three categories—Class N, Class F, and Class C—the fly ash used in this study falls under Class F because the total content of SiO_2, Al_2O_3, and Fe_2O_3 is 71.640% > 50%, SO_3 content is 1.892% < 5%, and CaO content is 15.118% < 18%.

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Table 7. ASTM C618 Chemical Composition Requirements for Fly Ash

Parameter	Class		
	N	F	C
Silicon dioxide (SiO_2) + Aluminum oxide (Al_2O_3) + Iron oxide (Fe_2O_3), min, %	70.0	50.0	50.0
Calcium oxide (CaO), %	Report only	18.0 max	>18.0
Sulfur trioxide (SO_3), max, %	4.0	5.0	5.0
Moisture content, max, %	3.0	3.0	3.0
Loss on ignition, max, %	10.0	6.0	6.0

Figure 3. Documentation of Fly Ash Testing

4. Coconut Fiber
   Coconut fibers were cleaned from impurities using clean water, then cut into ±3 cm lengths before being used in the mix design process.
5. Water
   Before being used in the paving block mix, the water must be clean and free from contaminants such as oil or silt.

3.2 Water Absorption Test Results

The water absorption test was conducted after the curing process, where specimens were dried and then re-immersed to determine the amount of absorbed water. Based on SNI 03-0691-1996, water absorption is calculated using Equation (1). Documentation during the test is shown in Figure 4.

$$Water\ Absorption = \frac{A-B}{B} \times 100\% \qquad (1)$$

Where A is the wet specimen weight (g) and B is the dry specimen weight (g).

Table 8. Water Absorption Test Results

Variation	Curing	Sample ID	Dry Weight (g)	Wet Weight (g)	Water Absorption (%)	Average (%)
			(w_1)	(w_2)	$w= (w_2-w_1)/w_1$	
I	Room Temperature	I.C1	216	218	0.93	1.38
		I.C2	218	220	0.92	
		I.C3	217	222	2.30	
	Water Immersion	I.C4	209	211	0.96	0.78
		I.C5	214	215	0.47	
		I.C6	215	217	0.93	
II	Room Temperature	II.C1	217	223	2.76	2.93
		II.C2	216	223	3.24	
		II.C3	216	222	2.78	
	Water Immersion	II.C4	239	240	0.42	0.56
		II.C5	237	238	0.42	
		II.C6	238	240	0.84	
III	Room Temperature	III.C1	226	229	1.33	2.10
		III.C2	229	233	1.75	
		III.C3	216	223	3.24	
	Water Immersion	III.C4	233	235	0.86	0.57
		III.C5	237	238	0.42	
		III.C6	230	231	0.43	
IV	Room Temperature	IV.C1	219	225	2.74	2.75
		IV.C2	225	230	2.22	
		IV.C3	213	220	3.29	
	Water Immersion	IV.C4	211	212	0.47	0.47
		IV.C5	217	218	0.46	
		IV.C6	213	214	0.4	

Figure 4. Documentation of Water Absorption Testing

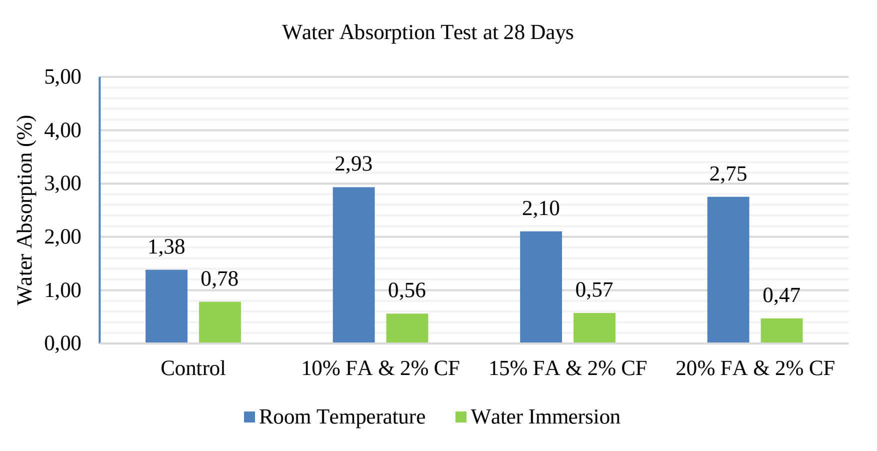

Figure 5. Water Absorption Test Results Diagram at 28 Days

The analysis results of this study, as shown in Table 8 and Figure 5, indicate that the water absorption test for paving blocks with room temperature curing and water immersion curing in Variation I (control) yielded average absorption values of 1.38% and 0.78%, respectively. In Variation II (10% FA and 2% CF), the results were 2.93% and 0.56%. In Variation III (15% FA and 2% CF), the values were 2.10% and 0.57%. Finally, in Variation IV (20% FA and 2% CF), the results were 2.75% and 0.47% for each respective curing method.

3.3 Compressive Strength Test Results

The compressive strength test in this study was carried out at the Mercu Buana University Laboratory using a Compression Testing Machine. Based on SNI 2847-2013, the compressive strength value can be calculated using Equation 2, while the test results are presented in Table 9. Documentation of the testing process is shown in Figure 6.

$$P = \frac{F}{A} \qquad (2)$$

where P is the compressive strength of the material (N/m^2 or MPa), F is the maximum compressive load (N), and A is the cross-sectional area of the material (m^2).

Table 9. Compressive Strength Test Results

Variation	Curing Method	Average Compressive Strength (MPa)		
		7 Days	14 Days	28 Days
I (Control)	Room Temperature	8.53	9.47	11.07
	Water Immersion	8.67	12.13	14.40
II (10% FA and 2% CF)	Room Temperature	8.63	10.54	11.58
	Water Immersion	8.92	14.29	14.89
III (15% FA and 2% CF)	Room Temperature	9.70	12.71	12.85
	Water Immersion	12.40	15.60	16.13
IV (20% FA and 2% CF)	Room Temperature	9.58	11.79	12.06
	Water Immersion	9.88	14.79	15.69

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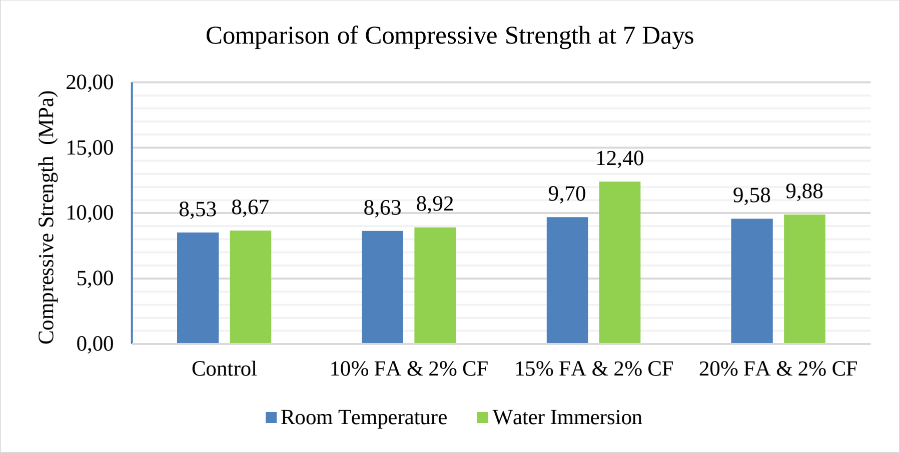
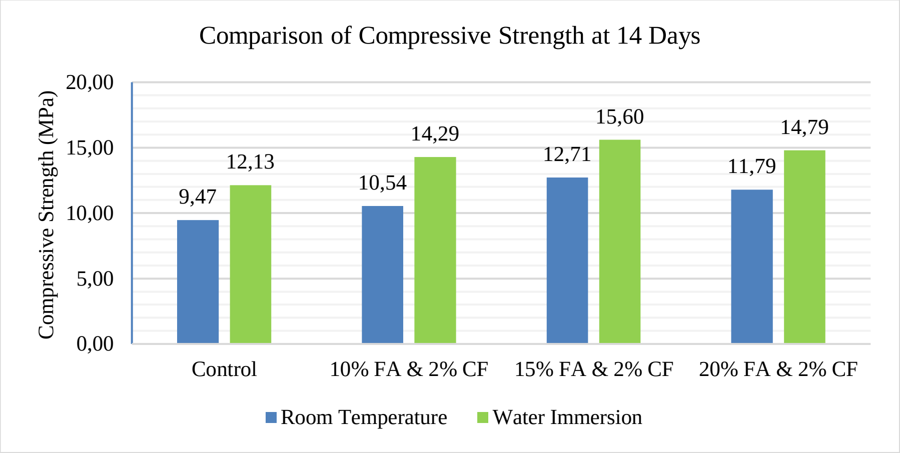
Figure 6. Documentation of Compressive Strength Testing



Figures 7. Compressive Strength Diagrams at 7 Days

The analysis results, as shown in Figure 7, illustrate the comparison of compressive strength at 7 days. It can be seen that the compressive strength of paving blocks increases with the addition of fly ash (FA) and coconut fiber (CF), with the highest results achieved by Variation III (15% FA and 2% CF) through room temperature curing and water immersion curing, reaching 9.70 MPa and 12.40 MPa, respectively. This indicates that the combination of these additives has begun to positively influence the early strength of the paving blocks. In Variation I (control), which did not include FA or CF, the compressive strength reached 8.53 MPa (room temperature) and 8.67 MPa (water immersion), serving as a reference for evaluating the effectiveness of the material additions. These results suggest that the use of FA and CF can enhance the performance of paving blocks from an early age. Furthermore, water immersion curing consistently produced higher compressive strength values than room temperature curing, indicating that adequate moisture is essential to support the hydration process optimally during the early hardening stage of the paving blocks.



Figures 8. Compressive Strength Diagrams at 14 Days

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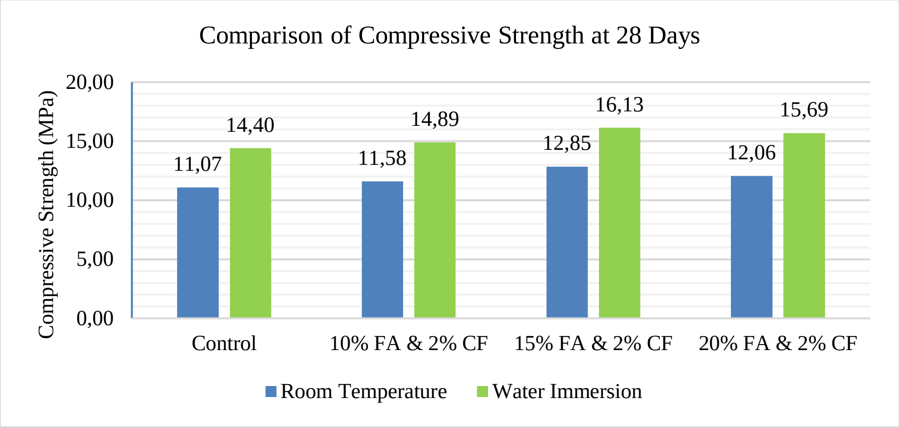
The analysis results, as shown in Figure 8, present a comparison of the compressive strength of paving blocks at 14 days. A significant increase in compressive strength is observed compared to the 7-day results shown in Figure 7, indicating that the hydration process and pozzolanic reaction have progressed more optimally. Variation III (15% FA and 2% CF) recorded the highest compressive strength through both room temperature curing and water immersion curing, at 12.71 MPa and 15.60 MPa, respectively, demonstrating the effectiveness of this composition in strengthening paving blocks during the intermediate phase. Meanwhile, Variation IV (20% FA and 2% CF) achieved the second-highest compressive strength under room temperature curing and water immersion curing, at 11.79 MPa and 14.79 MPa, respectively. These results indicate that using 15–20% fly ash provides optimal performance in improving paving block strength. Water immersion curing consistently yielded higher values, as the moist environment facilitates denser and more compact particle bonding.



Figures 9. Compressive Strength Diagrams at 28 Days

The analysis results shown in Figure 9 present a comparison of the compressive strength of paving blocks at 28 days. All variations exhibited an increase in compressive strength, indicating that the hydration process and chemical reactions between cement and fly ash had proceeded optimally. Variation III (15% FA and 2% CF) again achieved the highest results, with 12.85 MPa through room temperature curing and 16.13 MPa through water immersion curing. In contrast, Variation I (control) recorded 11.07 MPa with room temperature curing and 14.40 MPa with water immersion curing. Compared to the control variation, there was an increase in compressive strength of 16.08% for room temperature curing and 12.01% for water immersion curing. These results demonstrate that the mixture composition containing fly ash continues to provide a positive contribution to paving block strength, both in the short and long term. Furthermore, water immersion curing consistently produced higher compressive strength, as the maintained moist conditions promote the formation of denser paving blocks with minimal air voids, thereby significantly enhancing their strength.

3.4 Flexural Strength Test Results

The flexural strength test in this study was conducted at the Laboratory of Universitas Islam Syekh Yusuf, using a Compression Testing Machine with two support blocks at both ends of the beam and one loading block in the center. Based on SNI 4154-2014, the flexural strength value can be calculated using Equation 3. Documentation of the testing process is shown in Figure 10.

$$f_r = \frac{3PL}{2bd^2} \qquad (3)$$

fr is the flexural strength (MPa), P is the maximum test load (N), L is the span length between supports (mm), b is the width of the specimen (mm), and d is the height of the specimen (mm).

Table 10. Flexural Strength Test Results

Variation	Curing Method	Average Flexural Strength (MPa)
		28 Days
I (Control)	Room Temperature	2.27
	Water Immersion	3.19
II (10% FA and 2% CF)	Room Temperature	2.79
	Water Immersion	4.25
III (15% FA and 2% CF)	Room Temperature	2.50
	Water Immersion	3.70
IV (20% FA and 2% CF)	Room Temperature	2.37
	Water Immersion	3,52

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Figure 10. Documentation of Flexural Strength Testing

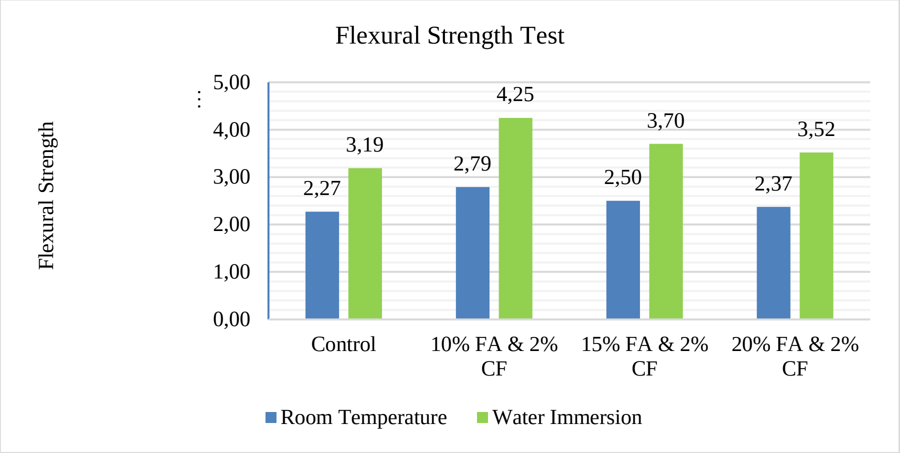

Figure 11. Flexural Strength Results Diagram at 28 Days

The analysis results shown in Table 10 and Figure 11 indicate the flexural strength values of paving blocks at 28 days. It can be seen that the addition of fly ash (FA) and coconut fiber (CF) significantly improves the flexural capacity of the paving blocks, particularly under water immersion curing conditions. Variation II (10% FA and 2% CF) achieved the highest flexural strength of 4.25 MPa with water immersion curing, demonstrating that this combination is the most effective in enhancing the paving block’s resistance to bending forces. In contrast, the control sample without additives only reached 3.19 MPa (water immersion) and 2.27 MPa (room temperature), confirming that mix modification greatly influences the performance improvement of paving blocks. Overall, all variations showed higher flexural strength results under water immersion curing compared to room temperature curing, indicating that moist curing conditions play an important role in forming denser and more flexurally resistant paving block structures.

4. Conclusion

The 28-day compressive strength test results of the paving blocks showed that the room temperature curing method produced compressive strength values of 11.07 MPa, 11.58 MPa, 12.85 MPa, and 12.06 MPa, respectively. Meanwhile, water immersion curing resulted in 14.40 MPa, 14.89 MPa, 16.13 MPa, and 15.69 MPa. The highest flexural strength, 4.25 MPa, was achieved with a mixture of 10% fly ash and 2% coconut fiber under water immersion curing. The use of fly ash and coconut fiber not only enhanced the mechanical strength of the paving blocks but also contributed to reducing industrial and agricultural waste. This combination proved effective in improving material performance while supporting sustainable development as an environmentally friendly solution. For paving block production, it is recommended to use a composition of 15% fly ash and 2% coconut fiber, as this variation achieved the highest compressive strength of 16.13 MPa (water immersion), which meets Grade C requirements according to SNI 03-0691-1996 and is suitable for pedestrian pavement applications. Nevertheless, composition selection should still consider the availability of local materials, production costs, and intended use. Future research is recommended to conduct similar tests while ensuring that all materials comply with SNI requirements—both fine aggregates, cement, and fly ash—to obtain results that are more representative of the mixture’s maximum potential and to allow a comparative analysis between the performance of mixtures using non-compliant materials and those using fully compliant materials. This will help determine the impact of material quality on the compressive strength, flexural strength, and overall physical properties of paving blocks.

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Reference

[1] M. R. N. Harimukti, “Komparasi Mutu Paving Block Penambahan Abu Batu Antara Metode Mekanis dan Konvensional,” *Skripsi*, p. Universitas Islam Indonesia, 2022.

[2] N. K. U. Nilawati and I. G. E. Dharsika, “Penerapan Paving Block Sebagai Perkerasan Jalan,” *Jurnal VASTUWIDYA*, vol. 4, no. 1, pp. 59–64, 2021.

[3] S. L. Sengkey, G. E. Kandiyoh, V. B. Slat, and C. Hombokau, “Pengaruh Substitusi Semen Portland terhadap Kinerja Paving Blok Geopolimer Berbahan Dasar Fly Ash Tipe F,” *Prosiding Seminar Nasional Produk Terapan Unggulan Vokasi*, vol. 1, no. 2, pp. 76–84, 2022.

[4] M. Solikin, “Analisis Pemakaian Kombinasi Fly Ash Tipe F Dan Slag 1:1 Pada Beton Geopolymer Dengan Na2SiO3 Dan NaOH Sebagai Alkali Aktivator: Sebuah Kajian Literatur,” *Dinamika Teknik Sipil*, vol. 14, no. 1, pp. 13–20, 2021, doi: 10.23917/dts.v14i1.15274.

[5] M. R. Olii, A. A. Wahab, I. Ichsan, R. A. Djau, and S. Nento, “Beton Hijau Menggunakan Fly ash sebagai Subtitusi Parsial Semen,” *Siklus : Jurnal Teknik Sipil*, vol. 9, no. 1, pp. 11–20, 2023.

[6] M. Isradi, A. Hidayat, and J. Prasetijo, “Guiding Paving Block Porous for Blind People,” *HOLISTICA – Journal of Business and Public Administration*, vol. 11, no. 1, pp. 79–86, 2020, doi: 10.2478/hjbpa-2020-0007.

[7] S. L. Sengkey, G. E. Kandiyoh, S. S. Peginusa, and D. Soukotta, “Pengaruh Gradasi Pasir Terhadap Kekuatan Tekan dan Penyerapan Paving Blok Geopolimer,” *Jurnal Serambi Engineering*, vol. IX, no. 2, pp. 8582–8589, 2024.

[8] N. Muin, Subaer, and Nurhayati, “Pengaruh Penambahan Semen Portland Terhadap Sifat Mekanik Geopolimer Berbasis Fly Ash,” *Jurnal Fisika dan Terapannya*, vol. 10, no. 2, pp. 98–111, 2023, doi: 10.24252/jft.v10i2.40262.

[9] S. R. Abdila, Syafwandi, M. Isradi, M. Sobirin, and A. Hidayat, “Soil Stabilization Using Gypsum and The Effect Based on The Unconfined Compressve Strength Values,” in *Proceedings of the International Conference on Industrial Engineering and Operations Management*, Harare, Zimbabwe, 2020, pp. 3338–3345.

[10] S. Rizki Abdila, M. Mustafa Al Bakri Abdullah, M. Faheem Mohd Tahir, R. Ahmad, Syafwandi, and M. Isradi, “Characterization of Fly ash and Ground Granulated Blast Slag for Soil Stabilization Application Using Geopolymerization Method,” *IOP Conf Ser Mater Sci Eng*, vol. 864, no. 1, 2020, doi: 10.1088/1757-899X/864/1/012013.

[11] Z. M. As-Shofa, “Pengaruh Penambahan Serat Serabut Kelapa Terhadap Kuat Lentur Dan Permeabilitas Genteng Beton Berbahan Limbah Bottom Ash Sebagai Pengganti Sebagian Semen,” *Tugas Akhir*, p. Universitas Islam Indonesia, 2024.

[12] L. P. Febrianty and A. O. Irlan, “Analisis Kuat Tekan Dan Kuat Tarik Belah Pada Beton Dengan Penambahan Serat Serabut Kelapa Dan Batu Apung,” *Construction Engineering and Sustainable Development*, vol. 5, no. 1, pp. 20–28, 2022, doi: 10.25105/cesd.v5i1.13936.

[13] S. R. Abdila *et al.*, “Evaluation On The Mechanical Properties Of Ground Granulated Blast Slag (GGBS) And Fly Ash Stabilized Soil Zia Geopolymer Process,” *Materials*, vol. 14, no. 11, pp. 1–19, 2021, doi: 10.3390/ma14112833.

[14] V. Fernando, E. Hunggurami, and T. M. W. Sir, “Pengaruh Perawatan Beton (Curing) Menggunakan Water Curing Dan Membrane Curing Terhadap Kuat Tekan Beton,” *Jurnal Teknik Sipil*, vol. 12, no. 2, pp. 137–144, 2023.

[15] Sugiyono, “Metode Penelitian Kuantitatif, Kualitatif, dan R&D,” *Bandung: Alfabeta*, 2013.

[16] E. J. Elizondo-Martinez, P. Tataranni, J. Rodriguez-Hernandez, and D. Castro-Fresno, “Physical and Mechanical Characterization of Sustainable and Innovative Porous Concrete for Urban Pavements Containing Metakaolin,” *Sustainability (Switzerland)*, vol. 12, no. 10, 2020, doi: 10.3390/su12104243.

[17] L. Moretti, P. Di Mascio, and C. Fusco, “Porous Concrete for Pedestrian Pavements,” *Water (Switzerland)*, vol. 11, no. 10, 2019, doi: 10.3390/w11102105.

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