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The Influence of Steel Fiber on the Characteristics of Paving Blocks

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Abstract: This study aims to (1) evaluate the effect of steel fibers on the characteristics of paving blocks and (2) determine the optimal mixture composition of steel fibers, cement, sand, and water. The composition variations of cement, steel fibers, and sand were 0%:30%:70%, 1%:30%:69%, 2%:30%:68%, and 2.5%:30%:67.5%, with a constant water-cement ratio (W/C) of 0.5. The characterization involved physical properties (density and water absorption) and mechanical properties (compressive and flexural strength). The results showed that water absorption and compressive strength for Sample A were 8.37% and 17.515 MPa, Sample B: 8.47% and 25.306 MPa, Sample C: 9.22% and 22.227 MPa, and Sample D: 9.92% and 23.388 MPa. Based on the SNI 03-0691-1996 standard, only Sample B met the quality requirement for grade B. The optimal composition for producing paving blocks with superior characteristics was 1%:30%:69% (Sample B), which achieved the lowest water absorption (8.47%) and the highest compressive strength (25.306 MPa). This result suggests that incorporating 1% steel fiber enhances paving block quality by reducing water absorption while improving mechanical strength.

Keywords: *Steel Fibers, Physical Properties, Mechanical Properties, and Paving Blocks*

1. Introduction

Paving blocks are a commonly used construction material for road surface layers alongside asphalt and concrete. In recent years, they have gained popularity over other pavement types, such as cast concrete and asphalt. This increasing preference is driven by several factors, including the environmentally friendly nature of paving block pavements contributing to groundwater conservation. Additionally, paving blocks offer advantages such as faster construction, ease of installation and maintenance, a wide variety of shapes that enhance aesthetic value, and cost-effectiveness. Moreover, the growing trend of developing tourist cities and vintage-themed urban areas, promoted by municipal and regional governments to boost tourism, has further increased the demand for paving block surfaces. Paving blocks are composed of Portland cement, water, and fine aggregates, with or without additional materials, provided they do not compromise the quality of the concrete.

Therefore, innovation is needed to enhance the compressive and flexural strength of paving blocks. One such innovation involves the incorporation of steel fibers, a material that has gained popularity for improving the stability of structural concrete. Numerous studies on structural concrete have demonstrated that adding steel fibers significantly enhances compressive and tensile strength.

2. Literature review

2.1. Paving Block

Paving blocks are a widely used surface hardening and ground covering material suitable for various applications, ranging from basic needs to specialized uses requiring specific specifications. They are commonly utilized for reinforcing and enhancing the aesthetics of urban sidewalks, paving residential areas, beautifying parks, and hardening parking lots and office areas. Additionally, paving blocks are used in specialized environments such as ports, container terminals, airports, bus terminals, and train stations (Handayasari & Artiani, 2019).

Paving blocks are a construction material made from a mixture of cement, aggregates, and water, with or without additional materials that do not compromise their quality. They serve as an alternative for covering or hardening ground surfaces. Paving blocks are also known as concrete blocks or interlocking blocks. As a surface hardening and covering material, they are widely used for various applications, ranging from basic needs to specialized uses requiring specific specifications (Handayasari, Artiani, & Putri, 2018).

Table 1. Physical Strength of Paving Blocks

Quality	Usage	Compressive Strength (Kg/cm^2)		Abrasion Resistance (mm/min)		Maximum Average Water Absorption (%)
		Average	Minumum	Average	Minumum	
A	Road Pavement	400	350	0,0090	0,103	3
B	Parking Area	200	170	0,1300	1,149	6
C	Pedestrian Walkway	150	125	0,1600	1,184	8
D	Urban Park	100	85	0,2190	0,251	10

(Source: SNI 03-0691-1996)

Based on SNI 03-0691-1996 (Standard, 1996), paving blocks are categorized into four types depending on their quality and application:

1. Grade A: Suitable for road surfaces.
2. Grade B: Intended for parking lots.
3. Grade C: Used for pedestrian pathways.
4. Grade D: Utilized in gardens and other non-structural applications.

The quality of a paving block is determined by its compressive strength (measured in MPa) and water absorption capacity. Higher compressive strength enhances durability, while lower water absorption improves the paving block’s overall strength and resilience.

The commonly used methods for manufacturing paving blocks for general use can be classified into two approaches:

a. *Conventional Method*

This method is the most commonly used by the community and is widely known as the *gablokan* method. The conventional paving block manufacturing process involves using a *gablokan* tool, where the compaction force depends on the manual labor applied by the workers. This method is widely adopted in small-scale home industries because it requires simple tools and an easy production process, making it accessible to anyone. The strength and density of the paving blocks produced depend on the force exerted by the worker during compaction. However, due to the manual compaction process, where a rammer is repeatedly struck into the mixture within a mold, this method can quickly lead to worker fatigue (www.dikti.depdiknas.go.id).

b. *Mechanical Method*

Commonly referred to as the press method within the community, this approach is less frequently used due to the relatively high cost of the required equipment. The mechanical method is typically employed by medium- to large-scale industrial manufacturers. In this process, paving blocks are produced using a compression apparatus, ensuring higher consistency, density, and strength compared to the conventional method.

2.2. Steel Fiber

Steel fiber is a type of fine steel fiber specially manufactured using advanced technology. This fiber is needle-shaped, with a length of approximately 140 mm and a diameter of ±0.0279 mm. Incorporating steel fibers in concrete enhances its quality by improving impact resistance, increasing flexural strength, and enhancing the shear strength of fiber-reinforced concrete beams (Nugraha & Antoni, 2007).

Steel fiber has been widely used as an additive in concrete mixtures. One of its key advantages is its rigidity, surpassing other fiber types, such as polypropylene fibers. Steel fibers come in various shapes and sizes, including round, flat, crimped (crimpled deformed), and hook-end types. This study uses hook-end steel fiber, as shown in Fig. 1. Bekaert manufactures the steel fiber, and its specifications are detailed in Table 2.

Fig. 1. Hook End Steel Fiber

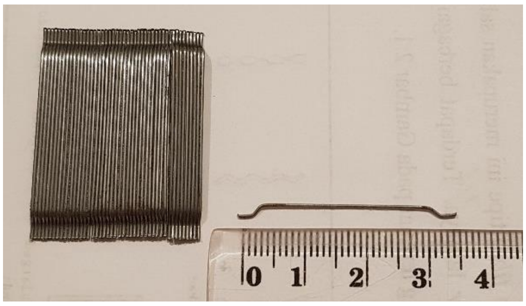

Table 2. Steel Fiber Specifications

Type	Length (l)	Diameter (d)	Aspect *ratio* (l/d)	Tensile strength (N/mm^2)	Amount of fiber per kilogram
3D-6535-BG	35 mm	0.55mm	65	1345	14531

3. Research method

The samples were fabricated in the Faculty of Engineering, Unissula laboratory, and tested according to existing standards. The tests performed included physical properties such as density and water absorption and mechanical properties such as compressive and flexural strength.

3.1. Research Procedure

3.1.1. Preparation of Steel Fiber

This study involved the production of paving blocks made from sand with various steel fiber mixtures, which were then tested per the SNI 03-0691-1996 standard. The parameters tested included compressive strength, flexural strength, density, and water absorption. The formulation of the base material mixture with steel fibers is detailed in Table 3.

Table 3. Proportions of raw materials used in the production of paving blocks

Specimen Code	Composition of steel fiber, cement, and sand mixture			Water-Cement Ratio (W/C)
	Steel fiber	Cement	Sand	
A	0%	30%	70%	
B	1%	30%	69%	0,5
C	2%	30%	68%	
D	2.5%	30%	67.5%	

3.1.2 Paving Block Production

The steps for producing paving blocks:
- Prepare the mixture for the paving blocks, including steel fibers, cement, sand, and water.
- Clean all the equipment to prevent contaminants from affecting the quality of the paving block mixture.
- Thoroughly combine the materials, ensuring the correct proportions per the specified formula.
- Pour the mixture into the molds that have been prepared in advance.
- Apply pressure to the mold using a press while smoothing the surface of the paving block mold.
- After filling the molds with the mixture, store them in a curing area for 2 days to allow the blocks to set, and then dry them for 28 days until fully hardened.

3.2 Physical Characterization Test Method
3.2.1 Density

Below are the steps for conducting the density test:
- Prepare the test sample.
- Weigh the sample's mass.
- Measure the volume of each sample variation.
- Calculate the density of each sample based on the collected data.
- Document the calculated density values.

3.2.2 Water absorption

To determine the water absorption capacity, the following procedure is performed:
- Prepare a container filled with water and the paving block sample, ensuring the sample has been dried for 28 days.
- Measure and record the initial mass of the paving block.
- Submerge the paving block in the water-filled container and let it soak for 24 hours.
- After 24 hours of immersion, remove the paving block and measure its mass.
- Calculate the water absorption value for each test sample based on the obtained data.
- Record the final water absorption values.

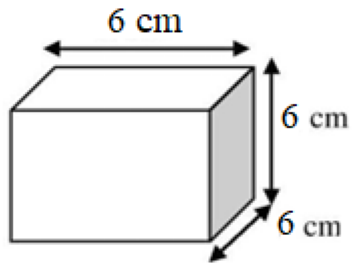

Fig. 2. Paving block samples for water absorption, density, and compressive strength tests

3.3 Mechanical Characterization Testing
3.3.1 Compressive Strength Testing

To determine the compressive strength of paving blocks, the following testing procedure is conducted:

- Prepare the paving block test specimens.
- Measure and record each sample's length, width, and height to be tested.
- Place the specimen ($3x3x3\ cm^3$) into the Universal Testing Machine (UTM) for compressive strength testing.
- Reset the load indicator to zero.
- Turn on the power and gradually apply a compressive force (F) from the top until the paving block fails while monitoring the load indicator.
- Record the maximum compressive load displayed on the gauge.
- Repeat the procedure three times using different test samples with varying compositions.

Fig. 3. Universal Testing Machine (UTM)

3.3.2 Flexural Strength Testing

To determine the flexural strength of paving blocks, the following test procedure is conducted:

- Prepare the test specimen.
- Measure and record the dimensions of each specimen.
- Weigh and document the mass of each specimen.
- Position the specimen on the testing platform.
- Apply load at a rate of $8\ kg/cm^2$ to $10\ kg/cm^2$ per minute.
- Reduce the loading speed before the specimen starts to bend.
- Remove the tested specimen and lower the plate to place the next specimen or lift the loading apparatus.
- Measure and record the width and height of the fractured cross-section at three different locations with a minimum precision of 0.25 mm, then calculate the average value.

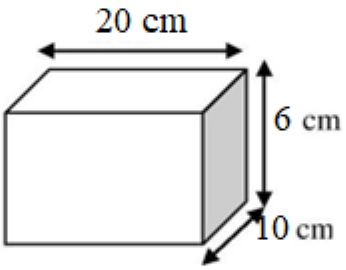

Fig. 4. Paving block samples for flexural strength test

4. Results

In this study, paving blocks were prepared using steel fiber as an additive. The physical and mechanical properties examined include density, moisture content, compressive strength, and flexural strength. The data and analytical results were obtained from tests on paving block samples containing steel fiber.

4.1 Characterization of Physical Properties

The physical properties of different compositions were evaluated by measuring density and water absorption.

4.2 Density

The results of density measurements for paving blocks incorporating steel fiber as a mixture are shown in Table 4.

Table 4. Measurement Results of Paving Block Density

Sample	Sample code	Density (g/cm^3)	Average density (g/cm^3)	SNI 03-2847-2002 (g/cm^3)
A	A1	2.167	2.172	
	A2	2.172		
	A3	2.178		
B	B1	2.145	2.176	
	B2	2.174		
	B3	2.210		
C	C1	2.223	2.228	2.20 – 2.50
	C2	2.228		
	C3	2.234		
D	D1	2.156	2.340	2.20 – 2.50
	D2	2.312		
	D3	2.553		

As presented in Table 4, the density values of paving blocks with steel fiber content of 0%, 1%, 2%, and 2.5% (samples A, B, C, and D) are 2.172 g/cm^3, 2.176 g/cm^3, 2.228 g/cm^3, and 2.340 g/cm^3, respectively. Based on the SNI 03-2847-2002 standard, the minimum required density is 2.20 g/cm^3, which is achieved by samples C and D containing 2% and 2.5% steel fiber. In contrast, samples with 0% and 1% steel fiber content do not meet this standard. The density measurement results for different variations of glass powder mixtures are illustrated in the following graph.

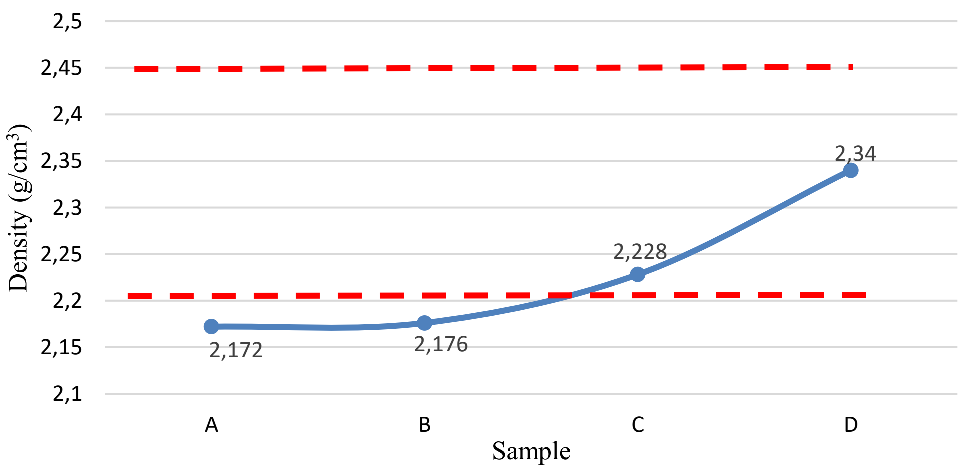

Fig. 5. Graph of Density Measurement Results for Paving Blocks

Fig. 5 illustrates that the highest density value is observed in the sample with 2.5% Fibersteel (Sample D), measuring 2.34 g/cm³, while the lowest density is found in the sample with 0% Fibersteel (Sample A), at 2.172 g/cm³. The density increases as the proportion of Fibersteel in the mixture rises. The sample with the highest Fibersteel content meets the density requirement specified in SNI 03-2847-2002.

Water Absorption

Based on the paving block production results incorporating glass powder, the water absorption measurements are presented in Table 5 below.

Table 5. Water Absorption Measurement Results of the Paving Blocks

Sample	Sample code	Water absorption (%)	Average water absorption (%)	SNI 03-0691-1996 (%) grade D
A	A1	9.57	8.47	Max. 10
	A2	8.04		
	A3	7.79		
B	B1	7.83	8.37	
	B2	8.31		
	B3	8.98		
C	C1	7.02	9.92	
	C2	12.96		
	C3	9.77		
D	D1	9.57	9.22	
	D2	9.34		
	D3	8.74		

As shown in Table 5, the water absorption values for the various Fiber steel mixture variations of 0%, 1%, 2%, and 2.5% (samples A, B, C, and D) are 8.47%, 8.37%, 9.92%, and 9.22%, respectively, which comply with SNI 03-0691-1996. Below is the graph showing the water absorption measurements for the different Fiber steel mixture variations.

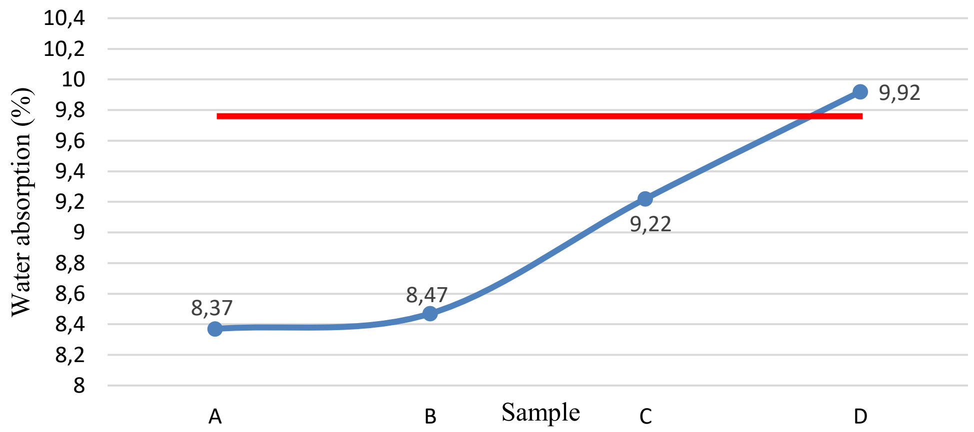

Fig. 6. Graph of Water Absorption Measurement Results for Paving Blocks

Fig. 6. shows, that the lowest water absorption value was found in the test sample containing 0% Fibersteel (sample A), which was 8.37%, while the highest absorption was found in the 2.5% Fibersteel mixture (sample D), at 9.92%. The variation in water absorption is affected by the proportion of Steel Fiber in the mix. A lower percentage of Fibersteel results in lower water absorption, while a higher percentage increases the absorption. In this study, Fibersteel proportions of 0%, 1%, 2%, and 2.5% all meet the SNI 03-0691-1996 standard for grade D paving blocks, suitable for use in gardens and other applications.

Mechanical Properties Characteristics

The compressive strength and flexural strength tests evaluate the mechanical properties of various mixtures or compositions.

Compressive Strength

Based on the tests conducted, the compressive strength of the paving block with Fibersteel mixture can be seen in Table 6 as follows:

Table 6. Compressive Strength Measurement Results of Paving Blocks

Sample	Sample code	Compressive strength (MPa)	Average compressive strength (MPa)	SNI 03-0691-1996 (MPa) Grade B
A	A1	16.106	17.516	
	A2	15.830		
	A3	20.599		
B	B1	20.283	25.306	
	B2	26.576		
	B3	29.059		
C	C1	20.388	22.227	Min 17.0
	C2	26.628		
	C3	19.666		
D	D1	23.725	23.388	
	D2	22.503		
	D3	23.935		

According to Table 6, the compressive strength values for the mixtures with 0%, 1%, 2%, and 2.5% Fibersteel (samples A, B, C, and D) are 9.22 MPa, 9.91 MPa, 10.12 MPa, 10.39 MPa, and 10.97 MPa, all of which meet the SNI 03-0691-1996 standard.

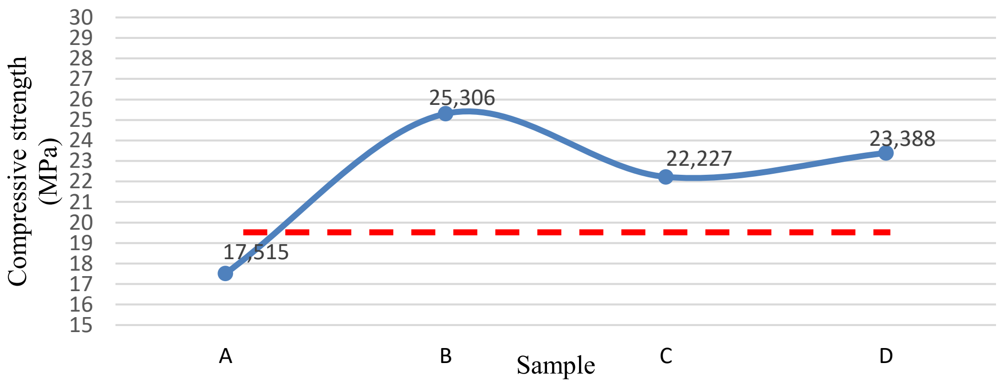

Fig. 7. Graph of Measurement Results of Paving Block Compressive Strength

As depicted in Fig. 7., the compressive strength improves in the sample containing 1% Fibersteel. The highest compressive strength is observed in sample B at 25.306 MPa, while the lowest is in sample A at 17.516 MPa. This suggests that the ideal Fibersteel concentration is 1%, resulting in the highest compressive strength and enhancing the paving block's quality.

Flexural Strength

The flexural strength test is conducted to determine the paving block's resistance to bending loads and the material's elasticity. The results are shown in Table 7. below.

Table 7. Measurement Results of Flexural Strength of Paving Block

Sample	Sample code	Flexural strength (MPa)	Average flexural strength (MPa)
A	A1	0,577	1,960
	A2	3,149	
	A3	2,155	
B	B1	4,655	4,457
	B2	4,213	
	B3	4,504	
C	C1	3,798	3,837
	C2	3,698	
	C3	4,016	
D	D1	4,129	3,988
	D2	3,564	
	D3	4,272	

As illustrated in Table 7 above, the flexural strength values for the sample mixtures A, B, C, and D are 1.960 MPa, 4.457 MPa, 3.837 MPa, and 3.988 MPa, respectively. The following is the graph depicting the flexural strength testing results for the Fibersteel mixtures.

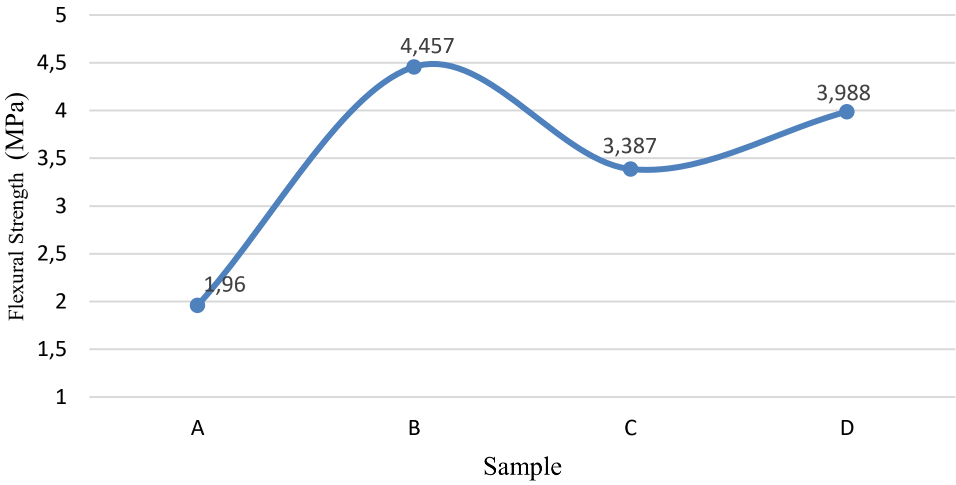

Fig. 8. Graph of Measurement Results of Flexural Strength of Paving Block

Fig. 8. shows an increase in flexural strength in the sample with 1% Fibersteel, while a decrease in flexural strength is observed with the 2% Fibersteel mixture. According to SNI 03-0691-1996 for Concrete Blocks (paving blocks), each grade requires no minimum flexural strength. Therefore, based on the flexural strength, pavements using the Fibersteel mixture do not fall within the quality category of SNI 03-0691-1996 for Concrete Blocks/Paving Blocks.

5. Discussion

Based on the study conducted on the production of paving blocks by mixing steel fibers (Fibersteel), it can be concluded that Fibersteel can improve the quality of the paving blocks. This is evidenced by several water absorption values meeting the requirements for grade D, and some compressive strength values that have met the standards for grade B, as specified in the SNI 03-0691-1996 standard for paving blocks. The maximum requirement for paving blocks, as regulated by SNI 03-0691-1996, for water absorption is 10%. Meanwhile, the minimum requirement for paving blocks, according to the same standard, for compressive strength is 17.0 MPa.

The characterization of the paving blocks, based on water absorption and compressive strength tests, showed the following results: Sample A had 8.47% water absorption and 17.516 MPa compressive strength, Sample B had 8.37% water absorption and 25.306 MPa compressive strength, Sample C had 9.92% water absorption and 22.227 MPa compressive strength, and Sample D had 9.22% water absorption and 23.388 MPa compressive strength. The highest water absorption was found in Sample C with a 2% Fibersteel mixture at 9.92%, while the highest compressive strength was found in Sample B with a 1% Fibersteel mixture at 25.306 MPa.

Referring to the test samples using Fibersteel, all paving blocks meet the quality requirements of Grade B as specified by the SNI 03-0691-1996 standard. The mixture of Steel Fiber (Fibersteel), cement, and sand in Sample B exhibits the most optimal characteristics due to its low water absorption and highest compressive strength values.

The paving blocks' density decreased during the mixing process with Steel Fiber (Fibersteel). The density values ranged from 2.172 g/cm³ to 2.34 g/cm³, which is close to the minimum standard set by SNI 03-2847-2002. This is due to the very low density of the Steel Fiber (Fibersteel) mixture.

A decrease in the water absorption rate of the paving blocks occurred as Steel Fiber (Fibersteel) was mixed in. The water absorption rate for the various mixtures from 0% to 2.5% still met the standards set by SNI 03-0691-1996 and can be classified as grade D paving blocks, which indicates that the maximum water absorption requirement for paving blocks is 10%.

The testing results show an increase in compressive strength as Steel Fiber (Fibersteel) was mixed in. The compressive strength values ranged from 17.516 MPa to 25.306 MPa. Based on samples A to D, the quality of the paving blocks produced meets the standards of SNI 03-0691-1996 and can be categorized as grade B paving blocks.

The bending strength values of the paving blocks with glass powder mixture varied. The highest bending strength was observed in the paving block with 1% Steel Fiber (sample B). This is because as the percentage of Steel Fiber increases, the paving blocks become less flexible.

6. Conclusion

Based on the results of the study, the following conclusions are presented:

1. The study reveals that Steel Fiber has an impact on the characteristics of paving blocks. Increasing the Steel Fiber content leads to improvements in density, compressive strength, and bending strength, with the optimal effect observed at a 1% concentration.
2. The ideal composition of Steel Fiber, cement, sand, and water for producing paving blocks with optimal characteristics is found in sample B, with a mixture ratio of 1%:30%:69%. This formulation resulted in paving blocks with the lowest water absorption and the highest compressive strength. The findings show that sample B meets the grade B quality standard for paving blocks as defined by SNI 03-0691-1996.
3. Paving blocks containing 1% Steel Fiber demonstrate superior quality compared to conventional ones without Steel Fiber. On the other hand, mixtures with 0%, 2%, and 2.5%

Steel Fiber did not meet the quality standards due to the failure of the compressive strength to meet the grade B paving block standard.

4. The addition of Steel Fiber enables conventionally made paving blocks to achieve a quality comparable to those made mechanically or by pressing (Grade B).

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