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Investigation of Physical and Mechanical Properties of Paving Blocks Reinforced with Sisal Fiber (*Agave Sisalana Perrine*)

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ABSTRACT

Paving blocks reinforced with sisal fiber (Agave sisalana Perrine) have been investigated in this study. The aim is to analyze the effect of sisal fiber addition on physical and mechanical properties such as tensile strength and compressive strength. Variations in the percentage of sisal fiber addition were tested to obtain the optimal composition. The method used was experimental through tensile stress and compression tests. The study results showed that adding sisal fiber significantly increased the compressive strength of paving blocks. Sisal fiber, with a length of 30mm, an average diameter of 0.26mm, and a weight of 0.0788 grams, obtained the highest tensile stress of the other variations, which was 207.27 Mpa. Meanwhile, the others were 292.26 Mpa, 193.27 Mpa, 191.77 Mpa, and the lowest was sisal fiber with an average diameter of 0.21 with a tensile stress of 175.14 Mpa. In terms of the quality of paving blocks after adding 3% sisal fiber, the average compressive strength of paving blocks increased to 13.2 Mpa, while paving blocks without additional sisal fiber only had a compressive strength of 8.9 Mpa. The increased strength of paving blocks with additional sisal fiber is due to the mixing of water-cement aggregates that enter the fiber pores, and hydrophilic and compatibility occur when dry and bind to each other. This study provides empirical data that supports the use of sisal fiber as a natural reinforcing material in paving block production and recommendations regarding the optimal percentage of addition.

1. INTRODUCTION

Paving blocks, a ubiquitous construction material, are used for a wide range of applications, from pedestrian paths to parking areas [1, 2]. This widespread use underscores the importance of understanding their strengths and weaknesses. Structurally, paving blocks have sufficient strength, especially in terms of compressive strength, but as ordinary concrete, paving blocks have the weakness of low tensile strength. On average, paving block damage occurs when receiving a load that exceeds capacity, and cracks occur. If this continues, the paving block will break or be damaged [3].

According to Benghida [4], concrete has been proven to be a sustainable construction material based on performance, strength, and durability requirements. The mixed design of a concrete structure has a direct long-term impact on its durability and performance. A tremendous concrete construction, with its long service life, no noticeable faults, and a low environmental impact, offers a reassuring sense of reliability. However, the concept of "concrete as a sustainable construction material" is not widely recognized, owing to the significant amount of CO_2 released by the Portland cement industry. The cement industry's energy-inefficient production process was projected to be responsible for 11.30% of global CO_2 emissions in 2015. This issue has encouraged research into more durable and environmentally friendly materials.

With the increasing awareness of the importance of utilizing natural and environmentally friendly materials, the research on using natural fibers as reinforcements in construction materials is increasingly intensive. According to Sun et al. [5], the qualities of natural composite materials provide a solid foundation for developing new applications and prospects for bio-composites or natural fiber composites (NFCs) in the 21st-century 'green' material environment. Natural fibers have recently gained popularity due to their prospective applications in biomedicine, biotechnology, and the environment. As a result, research and innovation in natural fiber composites have increased dramatically. Such interest is required due to the advantages of these materials over other materials, such as synthetic fiber composites. These advantages, including their low environmental impact and inexpensive cost, reassure us of their potential in various applications. Furthermore, most fibers have low density, specific strength, and modulus, with easily adjustable surfaces [6]. Therefore, the demand for ecological building materials, such as civil construction, proliferates in the market [7, 8]. Many researchers have researched these natural materials, focusing on their thermal and mechanical insulating qualities.

The most studied materials are jute [9-11], corn cobs [12, 13], straw bales [14, 15], hemp [16-19], coconut [20-23], straw [24, 25], date palm leaves [26-28], lontar palm [29], and sugar cane [30, 31]. The low environmental impact and cost-effectiveness of these natural fiber composites reassure us of their potential in various applications, instilling a sense of confidence in their future use.

In this regard, one attractive alternative is using natural fibers as reinforcement in paving blocks. For example, sisal fiber (Agave sisalana Perrine) has good mechanical properties, abundant availability, and relatively affordable prices [32]. The sisal plant (Agave sisalana) is one type of plant in the genus Agave, family Agavaceae. This plant originated in Mexico and was brought by the Spanish to Indonesia in the 17th century. This plant began cultivating in Indonesia in the 19th and 20th centuries and was used as an export commodity [33]. Sisal leaves are dark green and straight fleshy [21]. Sisal fiber is a plant with united stems and leaves, and strong fibers, and may grow on ground with a thin layer of cultivation (many surface stones) or crucial terrain. Sisal fiber from the agave sisalana plant has promising potential as a substitute for some synthetic materials in making paving blocks.

According to Sharma et al. [34], sisal fiber is a composite reinforcement material derived from non-wood natural fibers, and its raw materials are widely available worldwide. As a composite reinforcement material, sisal fiber has advantages, including good mechanical properties, the environment's ability to biodegrade fibers, low density, and ease of obtaining. What's more, it comes at a low price, making it an attractive option for various applications. Several studies have reported that sisal fiber can potentially reinforce polymer matrices [35]. Hidayati and Yulianti [36] said that the part of sisal that can be processed is the leaves because they contain fiber. The fiber in sisal can be processed into various traditional industrial products for making sacks, ropes, mats, and brooms. For more modern industries, sisal fiber is a raw material that can be processed into ropes for ship fleets, carpets, wrapping, clothing fillers, cable wrapping, and car interiors.

In general, sisal-polyester composites absorb three times more moisture than sisal-epoxy composites, resulting in different impact properties. Li et al. [37] improved the moisture resistance of sisal fiber through acetylation, reducing the moisture absorption from 11% to 5.35%. However, this led to a decrease in tensile strength from 445 to 320 MPa due to the loss of hemicellulose. Furthermore, Thomas and Jose [38] revealed that the strength of sisal fiber is better than other fibers and is resistant to high salt content. Therefore, several studies on the use of sisal fiber as a composite material have been carried out. For instance, sisal composites have been used in making car bumpers [39], textile materials [36], and concrete materials [40-42]. These studies have demonstrated the potential of sisal composites in various applications, highlighting their versatility and strength.

Exploring the potential of sisal fiber, a material with unique properties, this paper delves into its application in creating paving blocks with a range of variations. This innovative approach promises to enhance the quality of paving blocks [43]. The research presented here is centered on leveraging sisal fiber to bolster the physical and mechanical strength of paving blocks. The study delves into the effects on the physical and mechanical properties of paving blocks, with a focus on determining tensile stress and compressive strength. Sisal fiber was chosen for its widespread availability, abundance, and low economic cost in most parts of Indonesia. The sisal plants in Indonesia are primarily cultivated on Madura Island, South Malang, Jember, South Blitar, and Sumbawa Regency [44].

2. MATERIALS AND METHODS

2.1 Method used

This paper uses an experimental method in the Faculty of Engineering, Paulus Christian University of Indonesia (UKI Paulus) Makassar Laboratory. The quality of paving blocks with additional sisal fiber was tested to determine specific physical properties such as tensile strength and quality aspects such as compression tests before and after adding sisal fiber. The samples used for each variation were five pieces, so the total samples in this study were 20 pieces.

2.2 Mixing and sample preparation

The sisal plants used in this study came from Eban Village, Timor Tengah Utara (TTU) Regency, East Nusa Tenggara Province-Indonesia (Figure 1). The outer skin of the sisal plant was carefully processed into fiber, with a focus on avoiding damage to the valuable fibers. This was achieved by a slow and meticulous process of scratching the outer skin of the sisal plant, ensuring that the outer skin and pith were separated from the sisal fiber without causing any harm [45].

Figure 1. Sisal plant

The mixing and sample-making procedures are as follows:

1) First, sisal plants are taken from nature and then soaked. This soaking process is done with great care, ensuring that the outer skin of the sisal plant is preserved and processed into fiber by gently scratching the outer skin of the sisal plant. This separation of the outer skin and pith from the sisal fiber is done with utmost respect for the natural material, ensuring that the fiber is not destroyed. Figure 2 shows the finished raw material of sisal fiber after the outer skin and pith have been removed.
2) This raw material of sisal fiber is cut into 30mm lengths with varying diameters.
3) These pieces of sisal fiber material are crucially tested for tensile strength before mixing research materials. This test, a cornerstone of our study, aims to determine the tensile strength of the fibers used. The sisal fiber is placed on cardboard with a length of 5cm and a width of 1 cm. A hole is made in the middle of the

cardboard using scissors; then the fibers are placed on the cardboard that has been perforated and attached using paper tape. The fiber diameter used in this test is measured using a digital calliper with an accuracy of 0.1mm.

4) Finally, the paving block material mixture is made using Portland cement and fine aggregate in the form of sand from Takari. This mixing process uses a ratio of 1:5 sand weight with variations in the addition of sisal fiber of 0%, 3%, 5% and 7% of the weight of the cement that has been soaked for 28 days. This process includes weighing and mixing the materials. Each material is weighed according to its composition variation and mixed using a shovel until evenly mixed. Test objects are made using traditional tools with compaction loads used in making paving blocks. The mould tool is meticulously crafted according to the Indonesian National Standard (SNI) standard with a volume size of 20cm x 10cm x 8cm, ensuring the highest quality and consistency in the process. Compaction is carried out to fill the gaps or cavities in the recesses.

Figure 2 shows the finished raw material of sisal fiber after the outer skin and pith were removed. This raw material of sisal fiber was cut into 30mm lengths with varying diameters. The pieces of sisal fiber material were tested for tensile strength, a unique aspect of our research. Finally, a mixture of paving block materials was made using Portland cement and fine aggregate in the form of sand from Takari with a ratio of 1:5. The addition of sisal fiber was carried out with variations of 0%, 3%, 5% and 7% of the weight of the cement that had been soaked for 28 days. Test objects were made using traditional tools with compaction loads used in making paving blocks. The mould tool was made according to the standard size of the Indonesian National Standard (SNI) with a volume size of 20cm × 10cm × 8cm, and compaction was carried out until it filled the gap or cavity in the recess. This research is innovative in its approach to creating more sustainable and durable paving block materials.

(a) Sisal fiber processing results

(b) Sisal fiber diameter

Figure 2. Sisal fiber

2.3 Analysis of physical properties of materials

There are several physical properties of materials analyzed in this study, including:

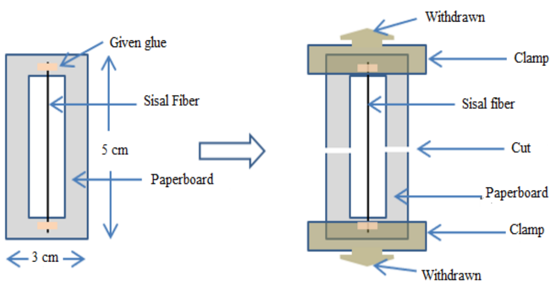
1) Fine aggregate sieve analysis (SNI 03-1968-1990), the purpose of which is to determine the division of fine aggregate grains (sand) and to obtain the size or percentage of fine aggregate grains. The procedure is as follows:
   a) Dry the test specimen in an oven at a temperature of (100 ± 5)°C until the weight of the test specimen does not change anymore (Constant weight). Constant weight is considered feasible if the condition of the object's weight is 3 times that of weighing and heating in the oven for two consecutive hours, and no weight changes are experienced.
   b) Weigh the test specimen with an accuracy of 0.01 grams.
   c) Filter the test specimen that passes through the sieve arrangement with the largest to the smallest sieve size. The sieve is vibrated with a machine for 15 minutes.
   d) Weigh the fine aggregate retained on each sieve.
2) Analysis of solid volume weight and loose volume weight of fine aggregate (SNI 03-4804-1998), the purpose is to determine the solid and loose volume weight of fine aggregate. The procedure is as follows:
   a) Dry the test object in the oven at a temperature of (110 ± 5)°C until the weight of the test object does not change.
   b) Remove the test object from the oven, then allow it to cool and weigh it to an accuracy of 0.5 grams.
   c) Place the measuring cylinder on a flat place to test the solid volume weight, put the test object in the cylinder, and then pound it until it is evenly distributed. Do this until the volume is full. Meanwhile, the test object is inserted into the cylinder until it is complete and flattened without compaction to test the friable volume weight.
   d) Weigh the cylinder of the test object and record the weight.
   e) Calculate the volume of the cylinder.
3) Silt content analysis aims to determine the content of mud in sand. A mud content of less than 5% is a provision in the regulations for using fine aggregate for making paving blocks. This test uses a sieve no. 200 mesh (mud content) in sand according to SNI (03-4142-1996). The procedure is as follows:
   a) Dry the test specimen in an oven at a temperature of (110 ± 5)°C until the weight of the test specimen remains constant, then soak it in water for 4 hours.
   b) The test specimen is inserted into the measuring object.
   c) Add hot water to the measuring cup to dissolve the mud.
   d) The cup is shaken to wash the sand so the mud separates.
   e) Store the cup on a flat surface and let the mud settle for 24 hours.

f) Measure the height of the sand and the height of the mud.

2.4 Mechanical testing

This study conducted two mechanical tests: fiber tensile strength testing and paving block compressive strength testing. The analysis of fiber tensile strength testing aims to determine the tensile strength of the fibers used in this study. The Techno Fiber Tensile Faster 50 N tensile testing machine tests the tensile strength by the ASTM D 3379-75 standard, which is the standard for fiber tensile test specimens, as shown in Figure 3. Furthermore, Figure 4 shows the sisal fiber tensile test setup experiment. The sisal fibers are placed on cardboard with a length of 5 cm and a width of 3 cm. A hole is made in the middle of the cardboard using scissors; the fibers are placed on the perforated cardboard and attached using paper tape. The diameter of the fibers used in this test is measured using a digital caliper with an accuracy of 0.1 mm.

Figure 3. Techno fiber tensile faster 50 N machine



(a) Test circuit

(b) Tensile test apparatus

Figure 4. Experimental set-up

For the compression test, 12 paving block specimens were prepared with specifications of 20cm × 10cm × 8cm using a Digital Compression Machine, as shown in Figure 5. Five specimen variations were tested on each test object, and the average value of the five tested specimens was taken. The quality of paving blocks with the addition of sisal fiber will be analyzed mathematically using Eq. (1).

$$\sigma = \frac{P}{A} \quad (1)$$

where,

σ = compressive strength of concrete block (kg/cm^2)
P = maximum load (kg)
A = cross-sectional area of test object (cm^2)

Figure 5. Digital compression machine

3. RESULTS AND DISCUSSION

3.1 Physical properties

3.1.1 Fine aggregate testing

Based on the results of the aggregate sieve analysis test, it is known that the Takari sand used in manufacturing test objects has met the requirements for the acceptable aggregate testing method SNI 03-1968-1990. SNI 03-1968-1990 is the Indonesian National Standard that regulates aggregate sieve analysis testing. This test aims to determine the grain size distribution of the aggregate, both fine aggregate (sand) and coarse aggregate. Information on grain size distribution is essential in planning and implementing various construction projects, especially in selecting the type of aggregate suitable for a concrete or asphalt mixture. Aggregate is a granular material used in construction, usually in the form of sand or gravel. Aggregate functions as a filler in a concrete or asphalt mixture, providing strength and stability to the building structure. The results of the fine aggregate analysis test are obtained in Table 1.

Table 1. Results of fine aggregate sieve testing

No.	Sieve Holes	Weight Left Behind		Cumulative Remaining Weight	Cumulative Pass
	(mm)	(gr)	(%)	(%)	(%)
1.	4.80	0	0	0	0
2.	1.18	70	7.5	7.5	92.5
3.	0.60	200	21.5	29	71
4.	0.30	410	44	73	27
5.	0.15	250	27	100	0
	Amount	**930**		**209.5**	**190.5**

Based on Table 1, it can be seen that the test and analysis results obtained a fine aggregate modulus (MHB) value of 2.095%. SNI 03-1968-1990 shows that the sand used in this test can be used because it meets the requirements as a fine aggregate according to the usual sand category with MHB between 1.5-3.8%.

3.1.2 Testing of solid volume weight and loose volume weight of fine aggregate

The testing of loose volume weight and solid volume weight of fine aggregate uses the SNI 03-4804-1998 method. The results of the loose volume weight and solid volume weight of fine aggregate can be seen in Table 2. It can show that the loose volume weight of fine aggregate is obtained at 0.00158 grams/cm³, and the solid volume weight of fine aggregate is obtained at 0.00197 grams/cm³. These results indicate that the solid volume weight of fine aggregate is greater than the loose volume weight of fine aggregate. This is because compaction is carried out by pounding in the solid volume weight test so that all pores are filled.

Table 2. Testing of solid volume weight and loose volume weight of fine aggregate

Description	Loose	Dense
Weight of the tube, gr (w_1)	0.280	0.280
Weight of cylinder + sand, gr (w_2)	1,900	2,300
Weight of sand, gr ($w_3 = w_2 - w_1$)	1.62	2.02
Volume of the cylinder, cm³ (V)	1,020.5	1,020.5
Volume weight of sand, gr/ cm³ (w_3/V)	0.00158	0.00197

3.1.3 Sludge content testing

Sludge content testing uses the SNI 03-4142-1996 method, where this test uses sieve No.200 (sludge content in sand). The test results for those who pass sieve No.200 can be seen in Table 3.

Table 3. Sludge content testing

Testing	Oven-Dry Sand (before Washing)	Oven-Dry Sand (after Washing)
$\frac{W_1-W_2}{W_2} \times 100\%$	W1	W2
	1.360	1.330
	2.255%	

According to Kanna et al. [46], the mud content in a fine aggregate is greatly influenced by the amount of mud in the aggregate. Excessive mud content in fine aggregate will affect the adhesion of the aggregate to the cement paste [47]. Excessive mud content in the aggregate can lower the mortar strength, so the desired quality still needs to be achieved. Therefore, it is necessary to check the mud content in the aggregate to meet the requirements. This has also been emphasized by Kumar and Kumar [48], that the mud content of the aggregate must meet the quality requirements by the requirements permitted by SNI S-04-1989-F, where for fine aggregate, the mud content is a maximum of 5%. In this study, the mud content of the fine aggregate was 2.255%. Thus, the fine aggregate used is categorized as suitable for making mortar because the percentage is less than 5%.

3.2 Mechanical properties

3.2.1 Tensile stress test

Figure 6 shows the results of tensile stress testing of sisal fiber. It can be seen that, sisal fiber with a length of 30mm and an average fiber diameter of 0.29mm obtained the highest tensile stress from other variations, which is 207.27 Mpa. Conversely, the lowest tensile stress is sisal fiber, with an average diameter of 0.21 of 175.14 Mpa.

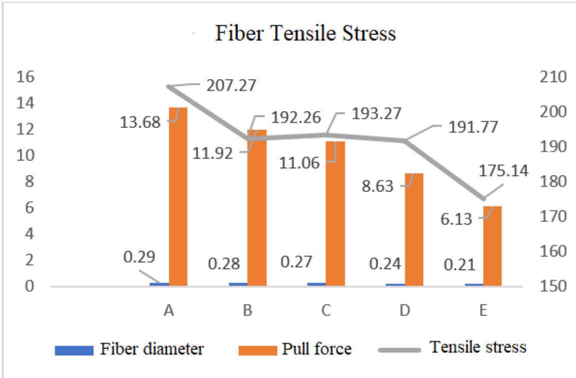


Figure 6. Sisal fiber tensile strength test

3.2.2 Compressive strength test

1) Calculation of paving block material mixture

In this study, the compressive strength testing of paving blocks was carried out before and after mixing sisal fiber. Therefore, the manufacture of paving blocks was carried out by calculating the mixture requirements for making paving blocks. It has been previously explained that the test specimens were made using a material proportion with a weight ratio of 1:5. At the same time, the need for sisal fiber was obtained from the percentage of sisal fiber to the cement volume converted to the cement weight. The calculation of the paving block mixture requirements is as follows:

- Paving volume = 20cm × 10cm × 8cm = 1,600 cm³
- Sand volume weight = 0.00189 gr/cm³
- Sand requirement for 1 paving block

$= \frac{5}{6} \times \textit{sand volume weight} \times \textit{paving volume}$

$= \frac{5}{6} \times 0.00189 \times 1{,}600 = 2.52\ \text{gr/cm}^3$ (1 paving)

- Sand requirement for 5 paving:

= 5 × 2.52 gr/cm³

= 12.6 gr/cm³

- Cement requirement for 1 paving:

= Cement requirement / 5

= 12.6 / 5 = 0.504 gr/cm³

- Cement requirement for 5 paving:

= 5 × 0.54 gr/cm³ = 2.52 gr/cm³

- Sisal fiber requirement with 3% variation:
- = 3% × cement weight

= 3% × 2.52 gr = 0.0756 gr

- Sisal fiber requirement with 5% variation:

= 5% × cement weight

= 5% × 2.52 gr = 0.126 gr

- Sisal fiber requirement with 7% variation

= 7% × cement weight

= 7% × 2.52 gr = 0.1764 gr

The results of the calculation of the mixture requirements of each element used in making paving blocks and the results are presented in Table 4. Based on this calculation's results, the cement weight in each fiber percentage variant is 0.504 gr, while the weight of sand used in each fiber percentage variant is 2.52 gr. Next, in sequence, the fiber weight with fiber variants of 3%, 5%, and 7% is 0.0756 gr, 0.126 gr, and 0.1764 gr.

Table 4. Paving block mix composition

Variation (%)	Cement (gr)	Sand (gr)	Sisal Fiber (gr)	Number of Test Objects (piece)
0	0.504	2.52	0	5
3	0.504	2.52	0.0756	5
5	0.504	2.52	0.126	5
7	0.504	2.52	0.1764	5
Amount				**20**

2) Paving compressive strength testing

The compressive strength testing in this study used 12 test objects from all treatments. Three samples were taken from each variation, where the variation used additional sisal fiber with a mixture ratio of 0%, 3%, 5%, and 7%. The compressive strength of the test object with a mixture of 0% Sisal fiber is shown in Table 5. The average compressive strength of paving blocks without fiber was obtained at 8.90 MPa with a measurement error percentage of 0.05%. Based on SNI 03-0691-1996, paving blocks with the lowest quality (quality D) are only suitable for use in parks and others but cannot be used for structural work [49]. Furthermore, paving blocks with a sisal fiber ratio of 3%, 5%, and 7% are shown in Table 6.

Table 6 compares the average compressive strength of paving blocks using fiber ratios of 3%, 5%, and 7%. Using sisal fiber, the average compressive strength for the 3% mixture of 13.2 Mpa was obtained with a remarkably low measurement error percentage of 0.09%. Furthermore, for both 5% and 7% mixtures, compressive strengths were obtained of 11.57 Mpa and 10.78 Mpa with each measurement error percentage of 0.04%. The three qualities of paving blocks reinforced with sisal fiber are still relatively low, with quality C for the 3% mixture and quality D for the 5% and 7% mixtures.

Based on SNI 03-0691-1996, this quality of paving blocks is only suitable for use for pedestrians and parks and cannot be used for structural work. Generally, paving blocks of quality C are usually made manually and have a minimum compressive strength of 12.5 mPa/K-125 (125kg/cm) with an average of around 15 mPa/K-150 (150kg/cm). Because it has a relatively low durability, this type of paving block can only be used as a non-structural part of construction, which means it is not used to support loads. Therefore, grade C paving blocks are widely used for light-traffic road areas, such as footpaths, pedestrian paths, or sidewalks. Just like grade C paving blocks, grade D paving blocks are also made manually by human power and have a minimum compressive strength of 8.5 mPa/K-85 (85/kg/cm) with an average of around 10mPa/K-100 (100kg/cm). Compared to other types, this paving block has the lowest compressive strength, so its use is more suitable for road areas with very low traffic loads [50, 51]. In addition, when reviewed before the addition of sisal fiber, there was an increase in compressive strength from 8.9 Mpa to 10.78 Mpa (7%), 11.57 Mpa (5%), and 13.2 Mpa (3%). Figure 7 shows the results of the compression test of paving blocks made for 6 months. It can be seen that the sisal fiber used is still sticky and strengthens the paving blocks. This proves that sisal fiber can increase the strength of paving blocks.

Description:

- $\bar{x}$ = Average amount
- d = Deviation ($d_1 = x_1 - \bar{x}$; $d_2 = x_2 - \bar{x}$; $d_3 = x_3 - \bar{x}$; ……… $d_n = x_n - \bar{x}$)
- D = Average deviation ($D = \frac{|d_1|+|d_2|+|d_3|..|d_n|}{n}$)
- % Error in measurement = $\frac{D}{\bar{x}} \times 100\%$

Figure 7. Results of the compression test of paving blocks stored for 6 months

Table 5. Results of compressive strength test of paving blocks without fiber (0%)

Sample Code	Cross-Sectional Area (mm)²	Maximum Load (kN)	Compressive Strength (MPa)
A1	6400	57.26	9.6
A2	6400	55.18	8.8
A3	6400	53.87	8.3
Σ		166.31	26.7
$\bar{x}$		55.44	8.9
d			d1=0.7; d2= -0.1; d3 = -0.6
D			0.47
% Error in measurement			0.05

Table 6. Compressive strength test results for paving blocks with fiber (3%)

Sample Code	Cross-Sectional Area (mm)²	Maximum Load (kN)			Compressive Strength (MPa)		
		3%	5%	7%	3%	5%	7%
A1	6400	72.35	71.06	66.64	11.3	12.02	10.44
A2	6400	93.9	70.82	65.25	14.7	11.41	10.21
A3	6400	87.17	69.97	67.84	13.6	11.27	11.7
Σ		253.42	211.85	199.73	39.6	34.7	
$\bar{x}$		84.47	70.62	66.58	13.2	11.57	10.78
d					d1= -1.9; d2= 1.5; d3 = 0.4	d1=0.7; d2= -0.1; d3 = -0.6	d1=0.7; d2= -0.1; d3 = -0.6
D					1.27	0.47	0.47
% Error in measurement					0.09	0.04	0.04

3.3 Discussion

Using natural plant fibers for reinforcement in composite products has various advantages. First, plant fibers are a local resource that is easy to access and less expensive than synthetic fibers. Plant fibers used in composite materials will have a lower environmental impact than conventional ones since they are renewable raw materials, biodegradable, have a neutral carbon balance, and require less energy [52]. In this paper, tests have been carried out on using sisal fibers to manufacture paving blocks with various compositions. The results of the study on the compressive strength of paving blocks with the addition of 3%, 5% and 7% sisal fibers with an average compressive strength of 11.85 MPa, increased compared to without using fibers of 8.9 MPa, or an increase in compressive strength of 2.95 MPa was obtained. This increase is based on the mixture of cement water absorbed by the fiber so that mutually necessary compactness causes the mixture to become strong. This is supported by previous research using lontar fibers to improve the quality of paving blocks produced by Eban, TTU Regency [53]. In addition, sisal fiber does not clump during mixing, so the binding process between cement and aggregate is quite strong.

The findings in this paper also revealed that the addition of sisal fiber did not exceed 3%. As stated in Table 6, the addition of 5% and 7% sisal fiber in paving blocks caused a decrease in compressive strength due to too much sisal fiber mixture, which could reduce the cement binding capacity. It has also been stated by Mydin [45] that the use of cement paste will be reduced when the amount of sisal fiber in lightweight foam concrete is more significant. Furthermore, the increase in drying shrinkage is also triggered by adding sisal fiber where there is no aggregate, and sisal fiber also contributes to improving the cement matrix [54]. Simultaneously, reducing the creation and pattern of cracks is also beneficial. Therefore, the presence of sisal fiber can reduce drying shrinkage. Using natural plant fibers for reinforcement in composite products has various advantages. First, plant fibers are a local resource that is easy to access and less expensive than synthetic or artificial fibers. Plant fibers used in composite materials will have a lower environmental impact than conventional ones since they are renewable raw materials, biodegradable, have a neutral carbon balance, and require less energy [55].

As a comparison, based on SNI 03-0691-1996, the higher the compressive strength value (Mpa), the better the quality of the paving block. The compressive strength at fiber variations of 3% (13.2 Mpa), 5% (11.57 Mpa and 7% (10.78 Mpa) can be included in the category of paving blocks with quality C and D due to the density of the sisal fiber additive so that the binding process between cement water and fiber occurs hydrophilic or mutually binding (Figure 7), and compatibility that makes the aggregate become maximum strength [56]. Compared with previous research by Adibroto [57] on adding wire fiber, coconut fiber, and plastic to paving blocks. At a variation of 2%, there was an increase in the compressive strength of paving blocks compared to regular paving blocks. However, the addition of wire fiber, coconut fiber, and 5% plastic to the paving block mixture did not provide a significant value on the addition of the compressive strength of paving blocks. It tended to reduce the compressive strength of paving blocks before adding coconut fiber and plastic.

Sisal is one of the many natural fibers that have shown promising results over the years; it has many favorable properties, including sustainability, high tensile modulus, and low cost [58]. Thomas has reported using sisal fiber as reinforcement in cement paste and concrete [38]. The fibers chemical, physical, and structural properties were studied in detail. His study reported that sisal fiber-reinforced composites have a strong basis in civil construction structural elements. In addition, it can be used as an alternative to steel because steel materials harm humans and animals. Compared with synthetic fibers and mineral asbestos, sisal fiber is considered economical in production and provides social and economic benefits. Previously, Sharma et al. [34] has reported that sisal has the potential to be an ideal replacement for suitable polymer composites. Sisal fiber composites have the maximum toughness of other fibers, which is about 1250 MNm^{-2}, and their strength is 580 MNm^{-2}. In addition, sisal fibers' physical and mechanical behaviour depends on their source, age, location, fiber diameter, experimental temperature, gauge length, and strain rate.

4. CONCLUSIONS

The current study investigates the physical and mechanical properties of sisal fiber from Eban Village, TTU Regency, East Nusa Tenggara Province, Indonesia, as well as the characterization of new composite materials derived from the different particle sizes of sisal fiber investigated. In general, the results indicate that sisal fiber has physical properties that increase the compressive strength of paving blocks. This research has allowed the scientific and industrial community to determine the feasibility and limitations of employing sisal fiber in various industrial applications. This is a new, cheap natural resource that the industry can utilize as a composite material for paving block materials. We have found that the mechanical properties increase along with the mixture ratio, reaching 3%, 5%, and 7% of sisal fiber material compared to without the addition of sisal fiber. Future research will consider testing the thermal properties of mixing brick making as a raw material to reduce heat radiation on building walls in tropical areas such as Indonesia.

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NOMENCLATURE

NFCs	natural fiber composites
SNI	Indonesian National Standard
MHB	fine aggregate modulus
P	maximum load, kg
A	cross-sectional area of test object, cm^2

Greek symbols

σ	compressive strength of concrete block, kg. cm^{-1}