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# The Potential of Sisal Fiber as an Eco-Friendly Concrete Reinforcement in East Nusa Tenggara-Indonesia

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**ABSTRACT**

Concrete has inherent limitations in resisting tensile forces and ductility, which are generally overcome by steel reinforcement. Adding fiber can improve concrete's mechanical properties, including compressive strength, tensile strength, and ductility. This study explored sisal fiber (Agave sisalana), abundant in North Central Timor, East Nusa Tenggara (ENT), Indonesia, as an admixture in concrete mixtures. The objective was to evaluate the effect of sisal fiber on the compressive strength of concrete and its potential for improvement. The experimental method was carried out at the Civil Engineering Materials Testing Laboratory of Kupang State Polytechnic, using cube specimens measuring 15 cm × 15 cm × 15 cm cured for 28 days. The variations of sisal fiber were 0%, 0.5%, 1%, 1.5%, and 2% of the cement weight. The results showed a significant increase in compressive strength. Regular concrete (0% sisal) had 7.64 MPa, below the K-125 standard (9.8 MPa) SNI 7394-2008. However, adding sisal fiber consistently increased the compressive strength, reaching a maximum of 12.56 MPa at 2% fibre. This demonstrates that local sisal fiber effectively improves concrete quality, even exceeding target standards, while supporting sustainable construction and empowering local resources.

## 1. INTRODUCTION

Rapid infrastructure development in regions like North Central Timor or Timor Tengah Utara, TTU (in Indonesia), NTT Province - Indonesia demands high-quality, economical, and sustainable building materials. Concrete is the primary choice in construction due to its ease of shaping, high compressive strength, and relatively low cost when using local raw materials [1]. However, conventional concrete has fundamental weaknesses, namely low tensile strength and ductility, so it requires reinforcement, usually steel, to withstand tensile forces [2]. Innovations in concrete technology continue to develop to overcome these limitations, one of which is the addition of fiber, known as fiber concrete. The addition of fiber aims to improve the mechanical properties of concrete, especially tensile strength and ductility, and provide superior post-cracking energy absorption capabilities.

Developing sustainable construction materials is a priority to reduce environmental impacts and efficiently utilize local natural resources. One promising approach is using natural fibers as reinforcing materials in concrete. Various studies have investigated natural fibers such as hemp [3-5], kenaf [6], banana [7, 8], and coconut fiber [9-11], showing significant potential. Natural fibers improve the brittle properties of cementitious composites, inhibit microcrack propagation, and enhance overall durability. Each type of fiber has unique characteristics that influence its performance in the concrete matrix. Adding natural fibers fundamentally improves the brittle structure of cementitious composites, providing enhanced ductility and superior post-cracking energy absorption capacity. This mechanism effectively inhibits the initiation and propagation of microcracks, thus preventing sudden failure and enhancing the overall durability of the composite. Among various natural fibers, sisal fiber (Agave sisalana) stands out for its strength, durability, and ability to grow in dry or degraded lands [12, 13]. Sisal fiber is abundant in dry climates such as East Nusa Tenggara, particularly in TTU Regency, but has not been optimally utilized [14]. This situation creates an excellent opportunity to integrate sisal fiber into the local construction industry, which improves material quality and supports the local community's economic development.

On the other hand, improving the mechanical properties of fiber-reinforced concrete must be examined at the macro and microstructural levels, particularly in the interaction between the fibers and the cement matrix. Microscopy, particularly the scanning electron microscopy (SEM) method, provides essential evidence for this analysis [15, 16]. SEM has become a crucial technique in materials research for investigating the interactions between fibers and the matrix. This type of microstructural analysis allows researchers to visualize the fiber-matrix interface zone, known as the interfacial transition zone (ITZ), at the micrometer scale. The ITZ is a critical area prone to microcracking due to its brittleness, and a strong interface between the fibers and the cement matrix is vital for effective stress transfer. SEM findings indicate that sisal fiber-reinforced concrete exhibits a denser microstructure, increasing its strength and durability.

In this regard, several studies have confirmed sisal fibre's important role in improving concrete's mechanical properties. However, there is significant variation in results between studies, depending on factors such as the quality of the base concrete and the fiber treatment. A study by Buttignol et al. [17] showed that in Ultra-High-Performance Fiber Reinforced Concrete (UHPFRC), fiber acts as a ductility-enhancing agent, not a compressive strength enhancer. In contrast, in this study, which used normal grade concrete (K-125), sisal fiber acted as a primary reinforcing agent, significantly increasing the compressive strength to meet structural standards. Furthermore, a study by Eid et al. [18] reported that chemical treatments, such as alkali treatment, can substantially increase the compressive strength (up to 45.4%).

In contrast, this study used local sisal fiber without chemical treatment, so the results reflect the baseline performance of sisal fiber in TTU. This highlights the potential that can be achieved through pretreatment. In addition, a decrease in concrete workability with fiber addition, as measured by a slump test, is also a common finding. A study by Thomas and Jose [13] explained that this decrease was caused by the hydrophilic nature of the fiber which absorbs water. However, this water absorption can be a beneficial mechanism, namely internal curing, which helps strength development and reduces shrinkage cracks later on, especially in dry environments such as NTT.

Regarding sustainability and recycled aggregates, Lyu et al. [19] investigated the effect of sisal fiber on concrete made with recycled aggregates (RAC) in the context of sustainability. This study introduced a significant variable absent in the TTU study: the type of aggregate used. While the TTU study utilized locally sourced natural aggregates, Lyu et al. [19] focused on recycled aggregates, representing a step towards more sustainable construction practices. Although specific data from these studies are limited, they illustrate the broader context of sisal fiber research, which combines natural and recycled materials to develop environmentally friendly construction materials.

This paper specifically examines the feasibility and impact of adding sisal fiber sourced from Eban Village, TTU, on the compressive strength of normal-grade concrete. Unlike previous studies on other concrete products, such as paving blocks [14], this study employs standard cube specimens to assess compressive strength. By concentrating on sisal fiber sourced locally from TTU, this research contributes uniquely to the literature, as the characteristics of the fiber can vary based on geographic location and growing conditions. Additionally, this study addresses technical questions related to improving concrete quality and emphasizes the potential for utilizing underexplored natural resources in the area, aligning with sustainable development goals.

## 2. STUDY AREA

Geographically, the NTT region is located at coordinates 9˚02'48" S and between 124˚04'02" E - 124˚46'00" E, with an area of 2,669.70 km², the boundaries of the TTU region are to the south with the South Central Timor Regency, to the north with the Ambenu region (Timor Leste) and the Sawu Sea, to the west with the Kupang Regency and South Central Timor, and to the east with the Belu and Malaka Regency. This geographical context is crucial for understanding the local relevance of sisal fiber development. The region is characterized by a predominantly semi-arid climate, which poses significant challenges for large-scale conventional agriculture due to low annual rainfall. However, these specific climatic conditions are highly suitable for the cultivation of agave sisalana, as sisal is a xerophytic plant that thrives in dry conditions and exhibits low tolerance to waterlogging (Figure 1). This environmental compatibility highlights unique opportunities for sustainable agriculture. The remarkable harmony between the specific ecological characteristics of TTU (semi-arid climate, availability of dry land) and the inherent growth requirements of sisal creates a powerful synergy. This synergy transforms what might traditionally be considered a regional agricultural challenge (limited rainfall for conventional crops) into a distinct opportunity to cultivate high-value and sustainable agrarian commodities, promoting economic resilience and ecological restoration [20].

**Figure 1.** Sisal plant

The majority of TTU's land area—approximately 74%, or 97,948 hectares—is designated for plantation and agricultural activities. The dominant soil types, particularly lithosols and grumusols, are known to be quite fertile. This suggests that there is ample land available for sisal cultivation, including underutilized marginal land. Despite its agricultural potential, TTU Regency continues to face significant socio-economic challenges, such as food insecurity and ongoing environmental degradation. In response, the local government has developed strategic programs aimed at advancing agriculture and optimizing the use of natural resources and the environment.

Sisal cultivation offers significant economic opportunities for local farmers in TTU Regency. It provides a sustainable source of income, mainly from marginal or drylands that are less productive for traditional food crops [21]. This aligns with TTU's broader agricultural development goals, which aim to improve farmers' well-being and enhance regional food security by indirectly providing income for purchasing food. In addition to these direct economic benefits, integrating local sisal cultivation with its use in regional construction materials can help establish a localized circular economy. This model reduces dependence on imported construction materials, which often have a greater environmental impact, thereby strengthening regional self-sufficiency, promoting local value chains, and minimizing transportation-related carbon emissions. Furthermore, the extensive fibrous root systems of sisal plants contribute to environmental restoration by binding soil, preventing erosion, and absorbing atmospheric carbon dioxide.

## 3. MATERIALS AND METHODS

### 3.1 Research method

This research utilized a quantitative experimental approach conducted at the civil engineering materials testing laboratory of the Kupang State Polytechnic. All testing procedures, including material preparation, mix design, specimen fabrication, and concrete mechanical property testing, were performed meticulously and in accordance with the Indonesian National Standard (INS) or SNI (in Indonesia) and relevant international standards. This adherence ensured the accuracy, validity, and reproducibility of the results. The controlled laboratory environment allowed for close monitoring of testing conditions, minimizing the influence of unwanted external variables.

### 3.2 Materials used

The primary materials used in the manufacture of concrete test specimens include:

Cement: Type I Portland cement is the concrete mix's binder.

Fine aggregate: Natural sand sourced from the Takari area of NTT is utilized. Before use, the fine aggregate undergoes testing to determine its properties, including sieve analysis by SNI 03-1968-1990 and specific gravity and water absorption tests following SNI 03-1970-1990. The fine aggregate is verified to be clean and free from organic matter and other hazardous substances.

Coarse aggregate: Natural crushed stone is used as the coarse aggregate. Its characteristics are assessed through sieve analysis based on SNI 03-1968-1990 and specific gravity and water absorption tests by SNI 03-1969-1990. The coarse aggregate is confirmed to meet the required gradation and durability standards.

Water: The water used for mixing the concrete and curing the specimens is clean and complies with water quality standards for concrete, as specified by ASTM C1602/C1602M. It is ensured to be free from oil, acids, alkalis, salts, organic materials, and any other substances that could harm the concrete or reinforcement.

Sisal fiber (Agave sisalana): Sisal fiber is incorporated as additional reinforcement. This fiber comes from sisal plants that grow abundantly in Eban Village, TTU Regency, NTT Province. The fiber extraction process is conducted traditionally by soaking (retting) to soften the outer skin, followed by manual raking to separate the fibers without causing damage. After extraction, the fibers are cleaned, dried, and cut to a uniform length of 30 mm to ensure a consistent distribution within the concrete mixture. Figure 2 shows sisal fiber in wet condition (Figure 2(a)) and in dry condition (Figure 2(b)).

(a) Wet condition (b) Dry condition

**Figure 2.** Sisal fiber

### 3.3 Mix design

The concrete grade planned for this study is K-125, equivalent to a characteristic compressive strength (*fc'*) of 9.8 MPa. The concrete mix composition refers to SNI 7394-2008 for regular concrete. SNI 7394-2008 establishes various concrete quality classifications based on its characteristic *fc'* in Mega Pascals (MPa) or K value (kg/cm²). Table 1 shows the mix proportions for 1 m³ of concrete: cement = 276 kg, sand = 828 kg, gravel = 1012 kg, and water = 215 L, with a water-cement ratio (w/c) 0.78.

**Table 1.** Concrete mix composition based on SNI 7394-2008 [22]

| Concrete Quality | Cement (kg) | Sand (kg) | Gravel (kg) | Water (Liter) | w/c Ratio |
|---|---|---|---|---|---|
| K 125 | 276 | 828 | 1012 | 215 | 0.78 |

The test specimens used in this study were cube-shaped with dimensions of 15 cm × 15 cm × 15 cm. The nominal volume of one concrete cube is 0.003375 m³. Based on the proportions for 1 m³ of concrete, the material requirements for one cube of the test specimen are calculated as follows:

- Cement: 276 kg/m³ × 0.003375 m³ = 0.9315 kg
- Sand: 828 kg/m³ × 0.003375 m³ = 2.7945 kg
- Gravel: 1012 kg/m³ × 0.003375 m³ = 3.4155 kg
- Water: 215 L/m³ × 0.003375 m³ = 0.7256 L

The percentage of sisal fiber added to the concrete mix is calculated based on the weight of the cement, namely 0% (as a reference/control mix), 0.5%, 1%, 1.5%, and 2%. For each variation of fiber percentage, 5 test specimens were made, so 25 specimens were prepared for the compressive strength test. Table 2 details the sisal fiber requirements for five cubes of test specimens in each variation, with the total cement weight for five cubes being 4.6575 kg.

**Table 2.** Sisal fiber requirements per 5 cubes of test specimen

| No. | Mixed Variation (%) | Fiber Weight (kg) |
|---|---|---|
| 1. | 0 | 0 |
| 2. | 0.5 | 0.023 |
| 3. | 1 | 0.047 |
| 4. | 1.5 | 0.070 |
| 5. | 2 | 0.093 |

### 3.4 Test specimen preparation

The process of preparing test specimens involves mixing the concrete mixture and forming the specimens, which is carried out through the following steps:

1. Material dosing: All materials (cement, sand, gravel, water, and sisal fiber) are accurately measured according to the specified proportions in the mix design.
2. Mixing the mixture:
   - Cement and sand are placed in a concrete mixer and mixed until they form a homogeneous blend.
   - Coarse aggregate (crushed stone) is added, and the mixer is rotated until all components are thoroughly combined.
   - Sisal fiber is gradually introduced into the mixer while it rotates, then gradually adding water until all the water is incorporated.
   - The mixer is rotated for approximately 10 minutes to

ensure all components are evenly and homogeneously mixed. The mixer is occasionally stopped and turned throughout this process to maintain the mixture's homogeneity.
3. Workability testing: Once the mixture is homogeneous, a slump test is performed on a portion of it to assess workability. During the slump test, the mixer continues to rotate to maintain the homogeneity of the remaining mixture. The required slump value for this study is between 25 and 75 mm, according to standards for pavements and floor slabs.
4. Casting of test specimens: The homogenized concrete mixture is cast into molds measuring 15 cm × 15 cm × 15 cm. Compaction is performed according to standards (e.g., by tamping or vibration) to eliminate air voids and ensure optimal density.
5. Curing: All test specimens are cured using a water immersion (water curing) immediately after casting, continuing until 28 days after testing. This curing method follows SNI 03-2834-2000 to ensure optimal cement hydration, allowing the concrete to achieve its design strength.

### 3.5 Concrete compressive strength testing

The testing procedure adheres to the SNI 03-1974-1990 or ASTM C39/C39M standards and follows these steps:
1. Sample preparation: The concrete cubes are removed from the soaking bath and then air-dried or wiped dry. Each concrete sample's weight is measured and recorded. A visual inspection is conducted to identify any defects in the test specimen.
2. Sample placement: The concrete sample is placed centrally on the pressure plate of the compression testing machine, which can be a Universal Testing Machine or a Compression Testing Machine.
3. Load application: The testing machine is powered on, and the compressive load is applied continuously and smoothly, without shock, at a constant loading rate (e.g., 0.25 ± 0.05 MPa/s, as recommended by ASTM C39/C39M) [23], until the test specimen fails.
4. Recording results: The maximum load reached at the time of failure is recorded. The compressive strength of the concrete is calculated by dividing the maximum load by the cross-sectional area of the test specimen. Additionally, the crack pattern and type of failure are documented.

## 4. RESULTS

### 4.1 Material characterization results

The fine aggregate sieve analysis test was conducted according to SNI 03-1968-1990, the Indonesian National Standard outlining the methods for sieve analysis of fine and coarse aggregates. This standard serves as a guideline for determining the grain size distribution (gradation) of aggregates, including both fine aggregates (sand) and coarse aggregates (gravel), using a series of sieves. The primary objective of this test is to obtain data on the aggregate grain size distribution in terms of the percentage by weight of grains that pass through each sieve. This information is crucial for aggregate quarry investigations, mix planning, and concrete quality control. The testing process involves sequentially sieving or screening aggregate samples through a set of sieves with varying opening sizes. Once the sieving process is complete, the aggregate retained on each sieve is weighed. The results are then analyzed to calculate the percentage of aggregate passing through each sieve, summarized in Table 3.

**Table 3.** Results of fine aggregate sieve testing

| Sieve Holes (mm) | Weight Left (gr) | Weight Remaining (%) | Cumulative Passing (%) | Cumulative Remaining Weight (%) |
|---|---|---|---|---|
| 4.80 | 0 | 0 | 100 | 0 |
| 1.18 | 70 | 7.5 | 92.5 | 7.5 |
| 0.60 | 200 | 21.5 | 71 | 29 |
| 0.30 | 410 | 44 | 27 | 73 |
| 0.15 | 250 | 27 | 0 | 100 |
| **Amount** | **930** | | | **209.5** |

**Table 4.** Testing of the solid and loose volume weight of fine aggregate

| Description | Loose | Congested |
|---|---|---|
| Weight of cylinder, grams ($w_1$) | 0.280 | 0.280 |
| Weight of cylinder + sand, grams ($w_2$) | 1.900 | 2.300 |
| Weight of sand, grams ($w_3 = w_2 - w_1$) | 1.62 | 2.02 |
| Volume of cylinder, cm³ (V) | 1,020.5 | 1,020.5 |
| Volume weight of sand, grams/cm³ ($w_3$/V) | 0.00158 | 0.00197 |

Furthermore, the loose and dense volumetric weight tests of fine aggregate were performed using the SNI 03-4804-1998 method. SNI 03-4804-1998 is an Indonesian national standard that outlines the procedure for testing the bulk density and air voids in aggregates. This standard is crucial in civil engineering, particularly construction, as aggregates such as sand, gravel, and crushed stone are essential for producing concrete and mortar. The results of the solid and loose volumetric weight tests for the fine aggregate are presented in Table 4.

The results indicate a loose bulk density of 0.00158 grams/cm³ and a solid bulk density of 0.00197 grams/cm³. The difference between these values shows that the solid bulk density is higher due to compaction, which fills the pores. This characteristic is important in the design of concrete mixes.

The silt content in fine aggregates is evaluated using the SNI 03-4142-1996 method, an Indonesian National Standard specifying a testing procedure for the material passing the No. 200 (0.075 mm) sieve in aggregates. This standard determines the percentage of fine material, such as clay, silt, and dust, contained in aggregates, significantly affecting the quality of concrete, asphalt, and other construction materials. The primary purpose of this test is to ensure that the aggregate used in construction has a fine material content (mud and dust) that does not exceed the allowed limits. An excessive amount of fine materials can weaken the bond strength between the aggregate and cement, ultimately compromising the quality and durability of the concrete structure. According to Tables 3 and 5, the tests conducted on fine aggregate and sisal fiber indicate that all materials used in this study comply with the relevant standards. Takari sand, which has a fineness modulus (FM) of 2.095% and a silt content of 2.255%, lies within the limits established by SNI, thereby ensuring good aggregate quality for concrete mixes. This value falls within the typical FM range for standard sand (1.5 – 3.8), confirming that the sand used is suitable as a fine aggregate for concrete applications.

**Table 5.** Sludge content testing

| Testing | Oven-dried Sand (Before Washing) | Oven-dried Sand (After Washing) |
|---|---|---|
| $W_1$ | 1.360 gr | |
| $W_2$ | | 1.330 gr |
| $\frac{W_1 - W_2}{W_2} x100\%$ | 2.255% | |

### 4.2 Tensile strength testing of sisal fiber (agave sisalana)

Tensile strength testing of sisal fiber was conducted in the laboratory of the Faculty of Engineering, Paulus Christian University of Indonesia (UKI Paulus) using a Techno Fiber Tensile Faster 50 N tensile testing machine, by ASTM D 3379-75 standards. This testing is crucial to ensure that local sisal fiber has adequate mechanical properties as a reinforcing material. Table 6 shows that local sisal fiber from Eban Village, TTU, demonstrated adequate tensile strength, with the highest value reaching 205.78 MPa for an average diameter of 0.26 mm. Other diameter variations ranged from 190.86 MPa to 204.08 MPa. This characterization confirms that this local natural resource has strong potential for construction applications.

**Table 6.** Results of sisal fiber tensile strength test

| No. | Fiber Diameter (mm) | Cross-sectional Area (mm²) | Tensile Stress (MPa) |
|---|---|---|---|
| 1. | 0.28 | 0.062 | 204.08 |
| 2. | 0.26 | 0.053 | 205.78 |
| 3. | 0.27 | 0.057 | 193.27 |
| 4. | 0.24 | 0.045 | 190.86 |
| 5. | 0.20 | 0.032 | 194.59 |

### 4.3 Slump testing

Slump testing is conducted to measure the workability or consistency of fresh concrete mixes with various fiber mixtures. The required slump value for pavements and floor slabs is 25-75 mm. Table 7 shows that adding sisal fiber progressively reduces the slump value, indicating a decrease in workability.

The slump test results indicate that adding sisal fiber affects the workability of the concrete mixture. The slump of standard concrete, which contains 0% fiber, is 7 cm. However, with sisal fiber, the slump decreases: it measures 5 cm with 0.5% fiber, 2 cm with 1% fiber, 1.5 cm with 1.5% fiber, and 2.5 cm with 2% fiber. This reduction in workability is a common occurrence in fiber-reinforced concrete, as the fibers increase internal friction and reduce the flowability of the mixture. Despite this decrease, the slump values remain acceptable for applications such as pavements and floor slabs (25-75 mm). However, additional consideration is necessary regarding workability when using higher fiber percentages.

**Table 7.** Slump test results

| No. | Mixed Variation (%) | Slump Test (mm) |
|---|---|---|
| 1. | 0 | 70 |
| 2. | 0.5 | 50 |
| 3. | 1 | 20 |
| 4. | 1.5 | 15 |
| 5. | 2 | 25 |

### 4.4 Test object weighing results

Table 8 shows the test object weighing results. The weight of cube specimens measured before compressive strength testing showed consistent variation among different batches. The average weight of specimens made with standard concrete (0% fiber) was approximately 7.168 grams. In contrast, specimens that included sisal fiber had slightly higher weights, ranging from 7.380 grams to 7.640 grams. These weight variations may be attributed to minor differences in mix density or water absorption during the curing process, but overall, they indicate consistency in sample preparation.

**Table 8.** Test object weighing results

| Mixed Variation (%) | Sample Code | Weight (gr) | | Weight Difference (%) |
|---|---|---|---|---|
| | | Wet | Dry | |
| | A1 | 8,572.44 | 7,143.7 | 20 |
| 0 | A2 | 8,642.28 | 7,201.9 | 20 |
| | A3 | 8,554.41 | 7,158.5 | 19.5 |
| | B1 | 8,651.18 | 7,269.9 | 19 |
| 0.5 | B2 | 8,942.4 | 7,452.0 | 20 |
| | B3 | 8,794.4 | 7,452.8 | 18 |
| | C1 | 9,037.97 | 7,469.4 | 21 |
| 1 | C2 | 9,242.40 | 7,702.0 | 20 |
| | C3 | 9,047.09 | 7,602.6 | 19 |
| | D1 | 9,060.30 | 7,613.7 | 19 |
| 1.5 | D2 | 9,096.36 | 7,580.3 | 20 |
| | D3 | 9,131.40 | 7,609.5 | 20 |
| | E1 | 8,903.11 | 7,450.3 | 19 |
| 2 | E2 | 9,007.94 | 7,569.7 | 19 |
| | E3 | 8,988.12 | 7,490.1 | 20 |

This paper utilized only three specimens for each variation of sisal fiber percentage (0%, 0.5%, 1%, 1.5%, and 2%) to test the compressive strength of concrete. While the results demonstrate a clear trend of increasing compressive strength with the addition of fiber, the limited number of specimens raises several concerns:

- Statistical validity: The average results may not accurately represent the concrete population with only three specimens. A specimen with unusually high or low results could significantly skew the average, compromising the conclusions' accuracy.
- Material variability: Concrete is inherently variable due to the differing compositions of its ingredients (cement, sand, gravel, water) and the mixing process. A larger number of specimens would help account for this natural variability and provide a more precise understanding of the performance of sisal fiber concrete.
- Reliability of Results: If any of the three specimens experienced issues during preparation, curing, or testing,

the final results could be unreliable. Having more specimens would mitigate the impact of such errors and enhance confidence in the study's findings.

### 4.5 Compressive strength testing of concrete cubes

The compressive strength testing of concrete cubes at 28 days was the central focus of this study. Figure 3 illustrates the results of concrete strength tests with sisal fiber mixtures ranging from 0% to 2%. The results demonstrate a notable increase in compressive strength with the inclusion of sisal fiber. Concrete samples without sisal fiber (0%) had an average compressive strength of 7.64 MPa, below the K-125 concrete quality standard of 9.8 MPa, as referenced in SNI 7394-2008. This indicates that the reference concrete did not meet the specified quality requirements. However, adding 0.5% sisal fiber improved the average compressive strength to 9.47 MPa. While this value is still slightly below the target of 9.8 MPa, it represents a significant enhancement compared to the standard concrete mix, suggesting that sisal fiber begins to provide a beneficial reinforcing effect.

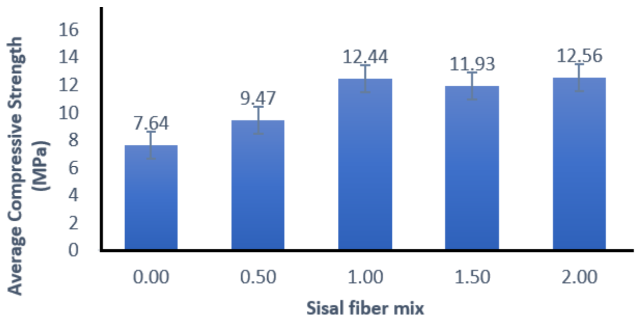


**Figure 3.** Results of concrete strength testing with sisal fiber mixture ratio

## 5. DISCUSSION

Research consistently shows that adding sisal fiber positively impacts the compressive strength of concrete. Concrete without sisal fiber only achieved a compressive strength of 7.64 MPa, which falls short of the K-125 quality standard of 9.8 MPa. However, with the incorporation of sisal fiber, the compressive strength significantly increased, reaching 9.47 MPa at 0.5% fiber content, 12.44 MPa at 1% fiber, 11.93 MPa at 1.5% fiber, and peaking at 12.56 MPa at 2% fiber. This increase suggests that sisal fiber is a bridging mechanism within the concrete matrix. When microcracks develop under compressive loading, the sisal fiber can bridge these cracks, delay their propagation and distribute stress more evenly throughout the material. This increase results in concrete's ability to withstand loads before experiencing brittle failure due to compressive strength. Overall, these findings demonstrate that incorporating sisal fiber significantly enhances the compressive strength of concrete. Notably, concrete reinforced with sisal fiber at 0.5% or greater not only meets but surpasses the K-125 quality standard, something that standard concrete without fiber fails to achieve. This underscores the practical potential of utilizing local sisal fiber to produce concrete with superior structural qualities.

Despite the overall increasing trend, a slight decrease in compressive strength was observed at 1.5% fiber (11.93 MPa) before it increased again at 2% fiber (12.56 MPa). This decrease may be attributed to the heavier average weight of sample D (7601.2 grams) compared to sample C (7591.3 grams) (Table 8). This phenomenon suggests that there may be an optimal point for fiber dispersion or that challenges in achieving homogeneity arise at higher fiber concentrations. When fiber is added in excess without proper mixing techniques, it can lead to issues such as fiber balling or increased void content due to a significant reduction in workability, ultimately diminishing the effectiveness of fiber reinforcement. While the study found that sisal fiber did not ball at a 0.5% addition, dispersion challenges might emerge at higher percentages. This could explain the slight drop in performance at 1.5%, followed by improved results at 2%, which may indicate better dispersion or a more prominent reinforcement effect at that level. An important finding of this study is that compressive strength exceeded the K-125 standard (9.8 MPa) across all sisal fiber variations from 0.5% to 2%. This indicates that locally sourced sisal fiber from TTU Regency can effectively produce concrete with structural qualities that meet or surpass standard requirements. This makes it a viable and superior alternative to conventional, fiber-free concrete tested in this study.

Furthermore, using sisal fiber as reinforcement in concrete has been widely researched worldwide. This study aligns with existing literature, which reports improvements in the mechanical properties of concrete due to the addition of sisal fiber. For instance, Lyu et al. [19] and Thomas and Jose [13] also observed that sisal fiber enhances the compressive strength of concrete. Eita and Attia [24] specifically explored how the content and length of sisal fiber affect concrete's compressive and tensile strength, demonstrating that these factors are crucial for performance.

This study makes a unique contribution by validating the performance of sisal fiber sourced from the TTU Region in NTT, Indonesia. While many studies on sisal have been conducted in various parts of the world—such as the case study by Ferraz-Almeida et al. [25] in Brazil, which characterized sisal fiber from different regions—the properties of natural fibers can vary significantly based on climate, soil type, and local processing methods. Therefore, this characterization and validation of sisal fiber from TTU Regency addresses a regional-specific knowledge gap, confirming that the potential of this local resource can be effectively utilized.

For comparison, in a previous study in 2024, Asrial et al. [14] showed an increase in compressive strength by adding 3-7% sisal fiber mixture, confirming that sisal fiber is a very effective reinforcement. The results of the study showed that the compressive strength of paving blocks with the addition of 3%, 5%, and 7% sisal fiber, with an average compressive strength of 11.85 MPa, increased compared to using 8.9 MPa fiber, or an increase in compressive strength of 2.95 MPa was obtained. However, it was emphasized that the maximum addition of sisal fiber was up to 3%, if it exceeded the average compressive strength would decrease. Meanwhile, in this study, with the addition of 0-2% sisal fiber, a higher compressive strength of 12.56 MPa was obtained in cube test specimens. This means adding 2% sisal fiber mixture is the optimal average strength in concrete. In addition, direct comparisons between studies need to consider differences in the type of test specimen (cube vs. cylinder) and the quality of the base concrete. However, both studies showed the positive effects of natural fiber.

Several other studies have explored sisal fibre surface treatments to improve chemical bonding, such as $Na_2CO_3$ [26], Sodium Hydroxide (NaOH) [27] or combinations of sisal with other materials, such as plastic waste [28], and nano-silica [29], for better performance. This study, which focused on traditionally processed sisal fiber without any special chemical treatment, provides a solid foundation for understanding the performance of local sisal fiber in its "native" condition and paves the way for further research that could explore bonding enhancement methods or material combinations for further optimization. Limitations of this study include the primary focus on compressive strength; testing of other mechanical properties, such as flexural tensile strength and splitting tensile strength, has not been conducted. Furthermore, this study did not include long-term durability analysis or the behavior of sisal fiber concrete under extreme environmental conditions. Future research could expand the scope of mechanical property testing, optimize fiber aspect ratio, evaluate fiber surface treatments, and conduct durability studies [30-32] and life cycle analysis for a more comprehensive sustainability assessment.

## 6. CONCLUSIONS

This research demonstrates that local sisal fiber from TTU Regency has significant potential to transform the construction industry while promoting sustainable development and boosting the local economy. The addition of sisal fiber has been shown to notably increase the compressive strength of concrete, consistently exceeding relevant quality standards. This advancement paves the way for developing stronger, more efficient, and more accessible construction materials, particularly in regions like TTU Regency that require resilient infrastructure.

Moreover, utilizing sisal fiber aligns with sustainable construction practices. As a renewable natural resource, sisal reduces dependence on more expensive conventional materials with a high carbon footprint. Its biodegradability and low density make it an environmentally friendly alternative to synthetic fibers or steel.

Most importantly, this research emphasizes the significant socio-economic impacts of sisal fiber production. The abundant sisal plants in Eban Village, TTU Regency, which have previously been underutilized, can now be transformed into high-value commodities. This shift creates new income opportunities for local communities through sisal cultivation and processing. With government support, sisal can evolve from a wild crop into a sustainable economic asset, thereby enhancing community well-being through the intelligent use of natural resources.

Overall, this research provides robust scientific data on the performance of TTU Regency sisal fiber in concrete and highlights a development model that integrates material innovation with local economic empowerment and environmental sustainability principles.

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## NOMENCLATURE

| | |
|---|---|
| ENT | East Nusa Tenggara |
| fc' | compressive strength |
| FM | fineness modulus |
| INS | Indonesian National Standard |
| NCT | North Central Timor |
| MPa | Mega Pascals |
| SEM | scanning electron microscopy |

### Greek symbols

| | |
|---|---|
| K | the concrete grade (in kg/cm²) |