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https://doi.org/10.5109/7395581

出版情報：Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES). 11, pp.639-644, 2025-10-30. International Exchange and Innovation Conference on Engineering & Sciences
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Experimental Investigation of *Musa textilis* Nee (Abaca) Textile-Reinforced Mortar as a Strengthening Material of Concrete Elements

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Abstract: *The growing demand for infrastructure, driven by population growth, necessitates sustainable construction practices to achieve net-zero carbon emissions by 2050. Textile-reinforced mortar (TRM) presents a greener alternative to fiber-reinforced polymers (FRP) due to its cost-efficiency, simplicity, and thermal resistance in retrofitting structures. However, conventional TRM systems use synthetic, non-biodegradable fibers. This study investigates residual abaca fibers as sustainable reinforcement in TRM. Abaca fibers were treated with 5% sodium hydroxide (NaOH) to enhance matrix bonding and woven into double-ply geotextiles with 15×15 mm grid spacing. One- and two-layer TRM systems were evaluated through direct tensile and concrete confinement tests. The one-layer system achieved 35.40% higher tensile strength, while the two-layer system exhibited 8.09% greater ultimate strain. Compressive strength of TRM-confined concrete increased by 25.52% and 51.32% for one- and two-layer systems, respectively. The use of natural abaca fibers in TRM contributes to the development of sustainable, high-performance materials for structural strengthening in green construction.*

Keywords: textile-reinforced mortar, abaca fiber, structural strengthening, green construction

1. INTRODUCTION

Reinforced concrete (RC) structures represent a major share of global infrastructure, many of which are now aging and deteriorating due to material degradation, reinforcement corrosion, and structural deficiencies. In Europe, over 80% of buildings were constructed before the 1990s and similar trends are observed in other developed regions [1]. These aging structures face failures in tension, compression, shear, and flexure, particularly in critical load-bearing elements like columns and beams. Such conditions necessitate reliable retrofitting strategies to ensure structural safety and prolong service life. Post-strengthening methods have gained increasing attention for enhancing structural durability while minimizing the economic and environmental impacts of demolition and reconstruction [2]. This is particularly important given that concrete production depletes natural resources and significantly contributes to carbon emissions and ecological disruption [3].

Textile-reinforced mortar (TRM) confinement has gained attention as a viable retrofitting method for strengthening concrete structures that enhances concrete strength, ductility, and energy absorption by limiting lateral expansion. TRM systems typically use synthetic or mineral-based textiles—such as carbon, basalt, and glass fibers—embedded in an inorganic mortar matrix [4,5]. However, these materials involve high embodied energy and are difficult to recycle, raising environmental and sustainability concerns [6]. As a result, the need to develop alternative, eco-friendly TRM materials has gained significant attention [7].

Abaca (*Musa textilis* Nee), commonly known as Manila hemp and native to the Philippines, offers a promising natural alternative due to its renewability, high tensile strength, and local availability. The Philippine Fiber Industry Development Authority (PhilFIDA) reports an average abaca fiber production of 53,997.73 metric tons annually, with 30–35% classified as residual waste. This study explores the use of residual abaca fibers—often discarded—as sustainable reinforcement in TRM systems. By integrating these fibers into a cementitious matrix, the research aims to create a nature-based TRM alternative that supports structural resilience while minimizing ecological impact.

2. MATERIALS AND METHODS

2.1 Abaca Textile

In this study, residual abaca fibers—typically discarded due to their failure to meet industrial textile standards—were repurposed as reinforcement material. The abaca textile fibers were treated with a 5% NaOH solution to enhance surface roughness and improve interfacial bonding with the cementitious matrix. Post-treatment, the fibers exhibited a tensile strength of 745.62 MPa (ASTM D3822) and a fineness of 281.07 dtex (ASTM D1577-07), as determined through experimental testing at the Philippine Textile Research Institute (PTRI) testing laboratories. The treated fibers were mechanically twisted into single-ply twine, then further processed into double-ply twined fibers with an approximate diameter of 5–5.5 mm. Using a Geoloom developed by DOST-PTRI, these fibers were manually woven into textiles with an optimized 15×15 mm grid spacing. The resulting abaca textile achieved a tensile strength of 28.95 kN/m, an elongation of 5.42% at maximum force at the cross-machine direction (CMD) through the wide-width test (ASTM D4595-17) and a mass per area of 952.17 g/m^2.

2.2 Specimen Preparation

2.2.1 TRM Coupon for Direct Tensile Test

The abaca textile, optimized using doubly-ply twined fibers and characterized by a grid spacing of 15 × 15 mm, was fabricated and subsequently cut into 100 × 500 mm strips to conform to the dimensions of the textile-reinforced mortar (TRM) coupons. A mortar matrix with a standard mix ratio of 1:3 (cement to sand) was prepared, wherein the sand was sieved using a No. 4 sieve and the cement through a No. 200 sieve, in accordance with ASTM specifications for fine aggregates. The dry constituents were mixed prior to the gradual addition of water, maintaining a water-to-binder ratio of 0.40. The mixture was stirred until the desired workability was achieved.

The fabrication process, shown in Figure 2.1., involved casting an initial 5 mm-thick mortar base layer, calculated to require 500 g of mortar based on the coupon dimensions and a unit weight of 2000 kg/m³. The mixture was evenly distributed within pre-oiled molds, after which the abaca textile was manually embedded into the fresh mortar. A subsequent 5 mm mortar layer was applied, resulting in a total coupon thickness of 15 mm. For specimens incorporating two layers of textile, the impregnation process was repeated, followed by an additional 5 mm mortar layer, yielding a final thickness of 25 mm.

Fig 2.1 Fabrication of TRM Coupons

Specimens were demolded after 48 hours and wrapped in plastic sheets, as shown in Figure 2.2, to prevent moisture loss, a precaution particularly critical for natural fiber textiles, which are susceptible to water absorption that could compromise the integrity of the TRM system. The specimens were then stored under controlled laboratory conditions for 28 days to complete the curing process prior to mechanical testing.

Fig 2 Plastic Sheet Curing of TRM coupons

2.2.2 Concrete Cylinder for Compressive Strength Test

For the engineering application of concrete confinement, cylindrical concrete cores (4 × 8 inches) were cast using a 1:2:4 mix ratio with small aggregate sizes and a high water-to-cement ratio, simulating low-strength or deteriorated structural conditions. The specimens were demolded after 48 hours and cured in water for seven days to ensure adequate hydration and early strength development prior to the application of confinement.

The fabrication of confined concrete cylinders was shown in Figure 2.3. To improve the bond between the concrete substrate and the TRM, mechanical scarification was performed. (a) Grooves approximately 10 mm deep and spaced at 1-inch intervals were created using a concrete grinder. A 10 mm gap was maintained at both ends of each specimen to ensure direct load transfer to the concrete core during testing. Styrofoam inserts supported the fresh mortar during curing and prevented dropping.

For the one-layer setup, (b) a 5 mm base mortar layer was applied, followed by (c) manual impregnation of the abaca textile. (d) A 10 mm outer mortar layer was then added, resulting in a total TRM thickness of 20 mm and increasing the specimen diameter from 100 mm to approximately 140 mm. In the two-layer configuration, a second textile layer was embedded between an additional 5 mm mortar layer and a final 10 mm outer coat, resulting in a total TRM thickness of 30 mm and a final diameter of approximately 160 mm. A flexible PVC guide ensured uniform application thickness. After 1–2 hours, the specimens were wrapped in plastic sheets to retain moisture and cured under controlled conditions for 28 days prior to testing, as shown in Figure 2.4.

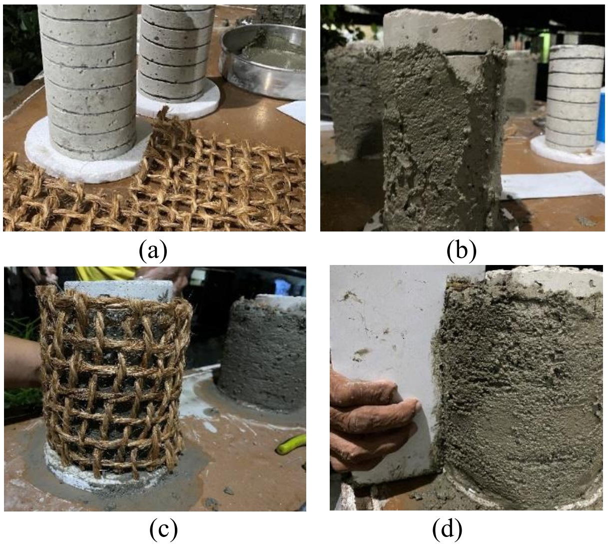

Fig 2.3 Fabrication of Confined Concrete Cylinder: (a) Preparation of Materials and Grooved Core, (b) 5mm mortar base, (c) Impregnation of Abaca Textile into the Mortar, and (d) 10mm mortar top.

Fig 2.4 Plastic Sheet Curing of Confined and Unconfined Cylinders

2.3 Testing

2.3.1 Direct Tensile Test

Direct tensile tests were conducted on TRM specimens measuring 500 mm in length and 100 mm in width, with thicknesses of 15 mm for single-layer and 25 mm for double-layer abaca textile reinforcement. The procedure followed the guidelines of RILEM Technical Committee 232-TDT [8], illustrated in Figure 2.5.

A total of 20 specimens were tested 10 with a single layer and 10 with two layers of abaca textile. To ensure uniform load distribution and prevent premature failure at the gripping zones, 4 mm-thick aluminum plates were adhered to both ends of each specimen, 100 mm from each edge. Testing was carried out using a Universal Testing Machine (UTM) at the Department of Public Works and Highways (DPWH) in Bataan. The load was applied under displacement control at an initial rate of 0.5 mm/min, with adjustments made by the operator as the test progressed.

Fig 2.5 Direct Tensile Test on TRM Coupons

2.3.2 Compressive Strength test

After the 28-day curing period, compressive strength tests were carried out to assess the structural performance of both confined and unconfined concrete cylinders. The testing procedure followed the guidelines of ASTM C39/C39M, ensuring standardized evaluation of cylindrical concrete specimens. Each cylinder was carefully positioned on the loading platform of compression machine, with attention to axial alignment to prevent eccentric loading, as shown in Figure 2.6. The compressive load was applied continuously and uniformly at a controlled rate until the specimen reached failure.

Fig 2.6 Compressive Strength Test

The maximum load sustained was recorded, and the corresponding compressive strength was calculated based on the original cross-sectional area of the concrete core. This testing procedure enabled the comparison of load-bearing capacities among unconfined samples and those confined with one or two layers of textile-reinforced mortar (TRM), thereby providing insight into the effectiveness of abaca textile confinement in enhancing compressive behavior.

3. RESULTS AND DISCUSSIONS

3.1 Tensile Properties of Abaca TRM

The results indicate significant differences in the tensile properties of abaca textile-reinforced mortar (TRM) systems, explicitly comparing those with 1L and 2L systems. The testing provided results for both load and displacement. To derive tensile strength the load was divided by the cross-sectional area of the composite material. The cross-sectional area for the 1L system had a thickness of 15 mm, while the 2L system had a thickness of 25 mm, with both having a width of 100 mm. The strain was calculated by dividing the displacement by the gauge length of 300 mm.

The 1L system exhibited an average maximum tensile strength of 3.8711 MPa, 35.40% higher than the 2L system's average of 2.8587 MPa. This suggests that the 1L system can better distribute stress, potentially due to more effective bonding and interaction between the single layer of textile and the mortar matrix. In contrast, the 2L system may experience stress overlap or weaker interfacial bonding, resulting in lower tensile strength. However, the 2L system demonstrated a higher average maximum strain of 0.1283, 8.09% greater than the 1L system's 0.1187, indicating enhanced ductility and energy absorption capacity before failure.

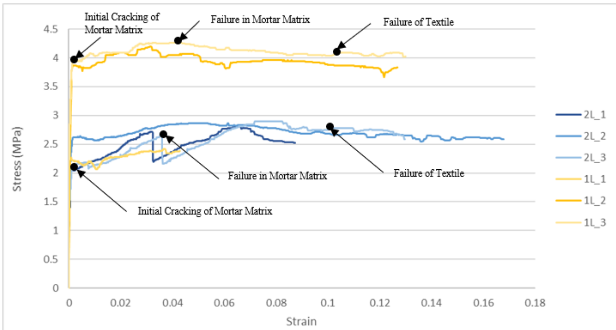

Fig 3.1 Tensile Stress-Strain Diagram

The stress-strain diagram in Figure 3.1 reveals distinct tensile behavior between the one-layer (blue) and two-layer (yellow) abaca TRM systems. In the initial phase, both systems exhibit a linear elastic region where stress increases proportionally with strain. This phase reflects the stiffness primarily governed by the mortar, as the abaca textiles have not yet been significantly activated. As the strain progresses, the curves deviate from linearity, indicating the onset of cracking in the mortar matrix. During this phase, the load is redistributed to the abaca textiles. The two-layer (2L) system demonstrates a smoother transition after cracking, suggesting enhanced stress redistribution due to the additional textile layer. Conversely, the one-layer (1L) system shows a more sudden transition, indicating a limited capacity for stress transfer once the mortar cracks.

The peak stress observed in the 1L system is higher, indicating that the single textile layer activates more effectively before failure, due to a better bond interaction with the mortar. In contrast, the 2L system shows lower peak stress but exhibits improved post-cracking behavior with a more consistent phase of residual strength. Both systems surpass the typical ultimate strain of concrete, which is approximately 0.003, highlighting the significant contribution of abaca textiles in enhancing the ductility and tensile performance of the mortar. The 1L system is better suited for applications that require higher immediate load resistance but offer lower deformation capacity. In contrast, the 2L system is ideal for applications prioritizing ductility, crack control, and energy absorption.

The 2-layer system demonstrates a saw-tooth behavior characterized by a sharp and linear drop in load, followed by a regain in strength due to sequential cracking and progressive stress redistribution, potentially from one textile to another. This behavior is illustrated in Figure 3.2 for the 2L_3 sample. The TRM system exhibits uniform stiffness in the (a) initial linear elastic region as the mortar matrix and textile layers work together to resist applied loads. However, (b) the mortar matrix cracks as the load increases, (c) causing localized stress redistributions. Each crack reduces the overall stiffness temporarily, leading to a drop in stress. Subsequently, the stress is transferred to the abaca textile layers, which then engage and carry the load, resulting in stress recovery. Moreover, (d) another major crack appears in the other part of the system.

This behavior indicates the progressive failure mechanism of the TRM system, where the mortar matrix provides initial resistance, and the textile layers maintain the structural integrity post-cracking. The saw-tooth pattern signifies the active role of abaca textiles in sustaining load capacity after matrix failure, demonstrating the composite material's potential for applications in structural strengthening where crack propagation control is essential. Failure mode (e) was predominantly observed when the abaca textile ruptured.

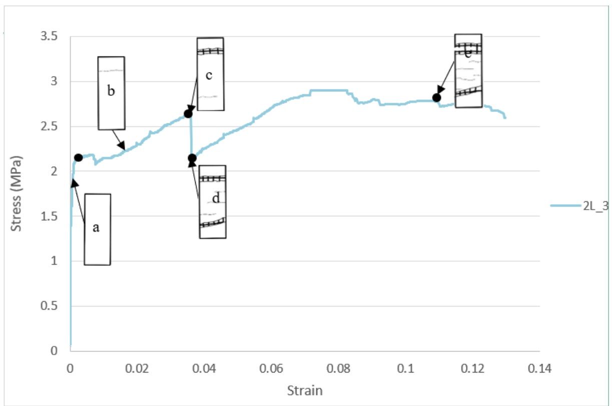

Figure 3.2 Stress-Strain Diagram at Sample 2L_3 highlighting the Saw-Tooth Phenomenon

3.2 Confined Properties of Concrete Cylinder

The results of the compressive strength tests for concrete confinement, as shown in Figure 3.3 through the boxplot, where the horizontal axis is the number of layers, and the y-axis is the compressive strength. It revealed a clear trend based on the number of abaca textile layers. The unconfined concrete with a low-strength design mixture (control sample) exhibited the lowest compressive strength, establishing the baseline performance with an unconfined compressive strength of 7.94 MPa. With the addition of a single layer of abaca textile, there was a significant increase in the average compressive strength of 9.96 MPa showing 25.52% increase, indicating the effectiveness of textile reinforcement. Furthermore, the double-layer configuration showed the highest average compressive strength of 12.01 MPa and a 51.32% increase of strength compared to the unconfined, with the median and range of values surpassing those of the one-layer TRM system. This consistent improvement in compressive strength with additional layers highlights the effectiveness of abaca textiles in enhancing concrete confinement.

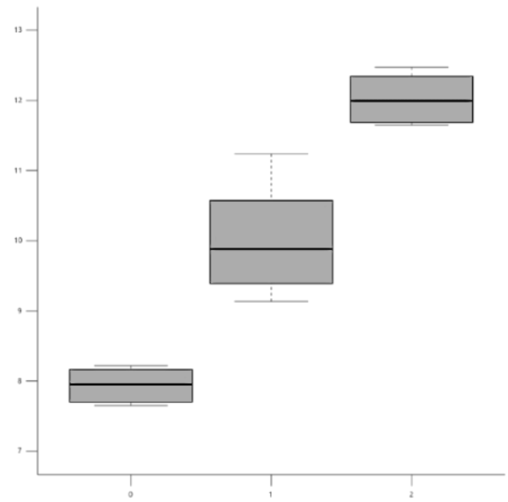

Fig 3.3. Influence of the Abaca Textile Layes on the Compressive Strength of Concrete Cylinders

3.3 Theoretical Calculation vs. Experimental Result

The theoretical calculations for confined concrete with 1-layer and 2-layer TRM systems were derived using a model adapted from FRP confinement theory. This adaptation was necessary due to the unavailability of the abaca textile's tensile modulus of elasticity (E). In the absence of this material property, the FRP model, which is based on externally bonded reinforcement, was employed to estimate the confinement effect of the TRM system.

The empirical equations utilized to determine the theoretical compressive strength of confined cylindrical concrete, denoted as f'_{cc}, are derived from the design-oriented model presented in Equation (3.1). Here, f'_{co} represents the compressive strength of the unconfined concrete obtained from experimentation, while (k) indicates the effectiveness coefficient and (m) signifies the power coefficient of the confinement ratio. The lateral confining pressure, denoted as fr, was calculated using Equation (3.2), where the tensile strength of FRP, f_{FRP}, was substituted with the tensile strength of the abaca TRM, f_{TRM}, based on the results from the direct tensile test of the abaca TRM system. Additionally, t represents the thickness of the confinement, and D is the diameter of the concrete core.

$$\frac{f'_{cc}}{f'_{co}} = [\,1 + k(\frac{f_r}{f'_{co}})^m] \qquad (3.1)$$

$$f_r = \frac{2 f_{FRP} t}{D} \qquad (3.2)$$

The theoretical confined compressive strength, f'cc, exhibited an increase in compressive strength compared to unconfined concrete, demonstrating abaca TRM's effectiveness in confinement. However, as this calculation was adapted from the FRP confinement model, discrepancies between the experimental and theoretical confined compressive strength may arise. In Equation (3.1), the effectiveness of confinement is influenced not only by the confining pressure but also by the confinement ratio, along with the effectiveness coefficient (k) and the power coefficient (m). Several design-oriented models exist for these empirical coefficients the best-fit values for the TRM system tested, with k=2.4 and m=1.0, derived from the model proposed by Cheng et al. (2000) in the paper of Li, G. (2006) [9] yielding results that closely align with the experimental data, as summarized in Table 3.1.

Table 3.1 Experimental vs. Theoretical Confined Compressive Strength

	Experimental (MPa)	Theoretical (MPa)	Difference
1-Layer	10.73	9.96	7.70%
2-Layers	12.06	12.01	0.39%

Theoretical Calculation on Confined Concrete with 1-Layer Abaca TRM System:

f'_{cc} is the compressive strength of the confined concrete
$f'_{co} = 7.94$ MPa
$k = 2.4$ (Cheng et. al)
$m = 1.0$ (Cheng et. al)
$f_{TRM(1\,Layer)} = 3.871$ MPa
$t = 15$ mm
$D = 100$ mm

Solving f'_{cc} using Equation (3.1)

$$f'_{cc} = f_{co}\,[\,1 + k(\frac{f_r}{f_{co}})^m]$$

$$f'_{cc} = 7.94\,MPa\,\left[\,1 + 2.40\left(\frac{1.161\,MPa}{7.94\,MPa}\right)^{1.0}\right]$$

$$f'_{cc} = \mathbf{10.73\ MPa}$$

Solving f'_r using Equation (3.2) for Equation (3.1)

$$f_r = \frac{2 f_{TRM} t}{D} = \frac{2*3.871\ \text{MPa}*15\text{mm}}{100\ \text{mm}} = \mathbf{1.161\ MPa}$$

Theoretical Calculation on Confined Concrete with 2-Layer Abaca TRM System:

f'_{cc} is the compressive strength of the confined concrete
$f'_{co} = 7.94$ MPa
$k = 2.4$ (Cheng et. al)
$m = 1.0$ (Cheng et. al)
$f_{TRM(1\,Layer)} = 2.8587$ MPa
$t = 15$ mm
$D = 100$ mm

Solving f'_{cc} using Equation (3.1)

$$f'_{cc} = f_{co}\,[\,1 + k(\frac{f_r}{f_{co}})^m]$$

$$f'_{cc} = 7.94\,MPa\,\left[\,1 + 2.40\left(\frac{1.715\,MPa}{7.94\,MPa}\right)^{1.0}\right]$$

$$f'_{cc} = \mathbf{12.06\ MPa}$$

Solving f'_r using Equation (3.2) for Equation (3.1)

$$f_r = \frac{2 f_{TRM} t}{D} = \frac{2*2.8587\ \text{MPa}*30\text{mm}}{100\ \text{mm}} = \mathbf{1.715\ MPa}$$

The sufficiency of confinement can be assessed using the confinement ratio proposed by Spoelstra and Monti (2007) [10]. According to their model, a confinement ratio smaller than 0.07 indicates insufficient confinement. The results presented in Table 3.2 demonstrate that the 1-layer and 2-layer TRM systems exceed this minimum threshold, confirming that the confinement provided is adequate for enhancing the concrete's performance.

Table 3.2 Minimum Confinement Ratio vs. Actual Confinement Ratio

	f_{co} (MPa)	f_r (MPa)	Confinement Ratio (f_r/f_{co})	Minimum Confinement Ratio
1-Layer	7.94	1.1613	0.146	0.07
2-Layers	7.94	1.7152	0.216	0.07

4. CONCLUSION AND RECOMMENDATION

The primary objective was to assess the feasibility of using abaca TRM as a sustainable and effective material for structural strengthening through concrete confinement. Key findings from the study are summarized as follows:

- The number of textile layers influenced the tensile properties of abaca TRM, with the one-layer (1L) system exhibiting 35.40% higher tensile strength, suggesting better stress distribution and interfacial bonding, while the two-layer (2L) system demonstrated an 8.09% increase in ultimate strain, indicating enhanced ductility and energy absorption capacity, thus highlighting the impact of layer configuration on the mechanical behavior and failure modes of the TRM system.
- The Abaca TRM system significantly improves concrete confinement, with the one-layer system increasing compressive strength by 25.52% and the two-layer system achieving a 51.32% increase compared to the unconfined control. Moreover, all specimens exhibited failure in the core, implying the TRM's ability to effectively confine the concrete core while accommodating surface damage. This highlights abaca textiles' effectiveness in enhancing concrete's structural performance through improved confinement.

Based on the research and challenges encountered, the following recommendations were drawn:

- Develop an automated twinning and weaving machine for producing abaca textiles to improve efficiency, reduce human error, and ensure consistency and quality in twined fiber and textile production.
- Explore the use of single-ply abaca textile for ease of application, reduced mass per unit area, and faster

production despite the superior performance of the double-ply configuration.

- Conduct fatigue and durability tests under different environmental conditions, such as moisture, temperature, and UV exposure, to assess the long-term performance of abaca TRM
- Incorporate a notch in the center of TRM coupons during direct tensile testing to ensure consistent failure in the specimen's middle.
- Explore the application of abaca TRM in real-scale structural elements like beams, columns, walls to assess its effectiveness and feasibility in practical construction.
- It is recommended to improve the theoretical calculations by testing additional specimens to better determine the optimal values of the confinement ratio exponent (m) and effectiveness coefficient (k) specific to the TRM system.

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