# NATURAL ORGANIC FIBER MESHES AS REINFORCEMENTS IN CEMENT-MORTAR MATRIX

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## Abstract

The use of fibers as reinforcing materials in cement-based composites has been widely explored. The challenge facing mankind today is focused on how to utilize natural organic fibers available locally in producing materials that would be appropriate for many low-cost construction project, especially in developing countries. This study is aimed at investigating the possibility of using cellulose fibers—namely, abaca and sisal—as oriented reinforcements in the form of meshes in cement-mortar matrices for the improvement of the overall performance of the composites. Rice Husk Ash (RHA) is also used as a replacement of part of the Ordinary Portland Cement (OPC) to reduce the decomposition of abaca and sisal fibers due to the alkaline environment of the cement matrix. Significant improvements in the overall performance of the cement-based composites were observed.

## Introduction

The use of fibers to reinforce brittle materials can be traced to biblical times when straws were used in brick manufacture [1]. Fiber-reinforced cements and concretes are today firmly established as construction materials. Since the early 1960s, extensive research and development have been carried out with fiber-reinforced composite materials leading to a wide range of practical applications. Considerable research has gone on in the field of fiber-reinforced, cement-based materials, and there is now an abundance of literature on the subject. Fibers such as sisal and coconut fibers used as reinforcement in the form of short fibers in cement matrices were explored [1]. Other natural fibers like coir, jute and hibiscus cannebinus in cement-mortar slabs were also investigated and results obtained show that the addition of these fibers increased the impact resistance of the plain mortar slab [2].

The major advantage of fiber reinforcement is to impart additional energy-absorbing capability and to transform a brittle material into a pseudo ductile material. Fibers in cement or in concrete serve as crack arrestors, which can create a stage of slow crack propagation and gradual failure [3]. Application of natural fibers to replace asbestos because of their availability in the tropical and subtropical parts of the world has been explored. Performance of mortar roofing tiles reinforced with natural fibers was studied [4]. Sisal fiber was used as reinforcement in cement-based composites and has shown that the composites are reliable materials to be used for structural materials. It has also been found that this material could be a substitute for an asbestos-cement composite [5]. Another study was done to analyze mechanical, physical and thermal performance of roofing tiles produced from cement-based matrices reinforced with sisal and eucalyptus fibers [6]. The study found that vegetable fibers are acceptable as substitutes for asbestos as reinforcements in cement-based sheets.

Replacement of asbestos fibers is seen as an area of priority research, particularly in developing countries where, apart from health problems, low-cost materials are urgently needed. Natural cellulose fibers have been produced either as a full or partial substitute for asbestos because they have similar characteristics such as high aspect ratio, high tensile strength, toughness, flexibility and, above all, buoyancy of the fiber in the cement [7]. Some developing countries, such as India, China and Russia have continued widespread use of asbestos. The most common is corrugated asbestos-cement sheets or "A/C Sheets" for roofing and for side walls [8]. Cellulose fiber-reinforced cement can provide the highest performance-to-cost ratio among fibrous cement composites for the replacement of asbestos. Past studies have shown that the reinforcement action of cellulose fibers in cementitious matrices is quite good relative to other fibers such as glass.

Cement-based materials suffer from one common shortcoming; they fail in a brittle manner under tensile stresses or impact loads or lack resistance to the propagation of cracks. The use of short, randomly distributed fibers is an effective method of strengthening brittle materials against cracking under stress. Broadly, the reason why weak, brittle materials are made tougher by very small additions of fibers is that cracks are deflected in the presence of fibers and, as a consequence, the toughness or ductility is dramatically increased. Fibers also give the cement composite material a very good plasticity in its fresh state after mixing the cement with water, making it possible to cast the material into different varying forms such as roofing sheets, floor tiles, etc. Realizing that short fibers offer effective reinforcing characteristics at improving the cement-based materials' properties, it is therefore essential to investigate whether reinforcing the cement-based materials with long-oriented fibers in the form of fiber meshes will give improved properties to the composites.

The most commonly used fibers are steel, glass, carbon and graphite, which contribute high strength and modulus for structural applications. However, these fibers are relatively expensive (which is critically important in third-world countries) compared to natural fibers. These conditions have resulted in a proliferation of exploratory studies on the use of natural fibers as reinforcement in fiber-reinforced composites. Cellulose fibers appear to be the most promising material because they are inexpensive and abundantly available in most of the developing countries.

# Fiber Reinforcement

Two types of fibers—abaca and sisal—locally obtained from the Philippines and Thailand, respectively, were used as reinforcing materials in making fiber-reinforced cement-mortar composites. The main variables in the study were fiber type and fiber content. The fibers used as reinforcements were in the form of meshes. The fiber content was represented by the number of mesh layers and varied in three different cases. The composites being investigated were of an OPC-RHA-sand matrix reinforced with fiber meshes. RHA was added to improve the durability of natural fiber-reinforced mortar [9].

The scientific study of natural fiber reinforcement has followed the developments with synthetic fibers. The reasons for putting fibers into cement-based materials are generally agreed to be as follows [10]:

- Improvement of flexure (bending strength)
- Improvement of impact toughness
- Control of cracking and change in failure behavior to give post-crack load-bearing capacity, and
- Change in the flow characteristics of the fresh material

## Abaca

Abaca, the common name for *Musa textilis*, is a species of banana native to the Philippines, grown widely as well in Borneo and Sumatra. Abaca fiber, unlike most other leaf fibers, is obtained from the plant leaf stalks (petioles). Although sometimes called Manila hemp, Cebu hemp or Davao hemp, it is not related to true hemp. Abaca fiber, known worldwide as Manila hemp, is obtained from the leaf sheath of the abaca plant. Abaca is indigenous to the Philippines and is similar to banana in appearance except that the leaves are upright, pointed, narrower and taper more than banana leaves. Abaca fiber is considered the strongest of the natural fibers. The length of the fiber varies from three to nine feet or more, depending on the height of the plant and the age of the leaf sheath. The color of the fiber ranges from ivory white to light and dark brown.

Abaca fiber, valued for its strength, flexibility, buoyancy, and resistance to damage in saltwater, is chiefly employed for ships' hawsers and cables, fishing lines, hoisting and power-transmission ropes, well-drilling cables and fishing nets. Some abaca is used in carpets, tables and fabrics mainly used locally for garments, hats and shoes.

**Figure 1. Abaca Plant and Abaca Fibers**

## Sisal

Sisal, the common name for *Agave sisalana*, is a plant of the agave family Agavaceae that yields a stiff fiber traditionally used in making twine, rope and dartboards. The term may refer either to the plant or the fiber, depending on context. It is sometimes incorrectly referred to as sisal hemp because hemp was for centuries a major source for fiber, so other fibers were sometimes named after it.

The plant's origin is uncertain; while traditionally it was deemed to be a native of Yucatan, there are no records of botanical collections from there. H.S. Gentry hypothesized a Chiapas origin, on the strength of traditional local usage [11]. In the 19th century, sisal cultivation spread to Florida, the Caribbean islands and Brazil, as well as to countries in Africa—notably Tanzania and Kenya—and Asia. The first commercial plantings in Brazil were made in the late 1930s and the first sisal fiber exports from there were made in 1948. It was not until the 1960s that Brazilian production accelerated and the first of many spinning mills was established. Today, Brazil is the world's leading producer of sisal [11]. There are both positive and negative environmental impacts from sisal growing.

Sisal fiber is valued for cordage use because of its strength, durability, ability to stretch, affinity for certain dyestuffs and resistance to deterioration in salt water. Sisal ropes and twines are widely employed for marine, agricultural, shipping and general industrial use. The fiber is also made into matting, rugs, millinery and brushes.

**Figure 2. Sisal Plant and Sisal Fibers**

## Experimental Investigation

The constituent materials used in this study were:

- Ordinary Portland Cement (OPC) Type I
- Rice Husk Ash (RHA) obtained by burning rice husk using the machine developed by We [12], and was used as a partial replacement of OPC
- Ordinary tap water
- Natural river sand passing ASTM sieve no. 50 and retained on sieve no. 100
- Rheobuild 1000 Superplasticizer
- Abaca and sisal fibers

The abaca and sisal fiber meshes were fabricated manually by using weaving frames especially designed for this study. Formworks for the composite plate samples were also especially designed. The casting of the test specimens was conducted manually using the specially designed molds. Abaca and sisal fiber composite plates were fabricated separately in three different variations of fiber contents (i.e., 2-, 4- and 6-layer fiber meshes). Control specimens with no fiber reinforcement were also fabricated for comparative purposes. For the investigation of the properties of fiber-mortar composite plates, 300 x 300 x 10mm plates were fabricated using the designed molds. After 28 days of curing in a humid room, the specimens were cut into 250 x 100 x 10mm plates. The plates were then allowed to dry for one day and then tested according to ASTM C78 / C78M [13]. Details of the testing program are shown in Table 1.

**Table 1. Testing Program of the Properties of Fiber-Mortar Composite Plates**

| Type of Plate | Fiber Content (Number of Fiber Mesh Layers) | Plate Dimension | Type of Test | Number of Specimens |
|---|---|---|---|---|
| No Fiber (control) | 0 | A | M | 3 |
| | | A | W | 3 |
| | | B | F | 3 |
| Abaca Fiber -Reinforced | 2 | A | M | 3 |
| | | A | W | 3 |
| | | B | F | 3 |
| | 4 | A | M | 3 |
| | | A | W | 3 |
| | | B | F | 3 |
| | 6 | A | M | 3 |
| | | A | W | 3 |
| | | B | F | 3 |
| Sisal Fiber-Reinforced | 2 | A | M | 3 |
| | | A | W | 3 |
| | | B | F | 3 |
| | 4 | A | M | 3 |
| | | A | W | 3 |
| | | B | F | 3 |
| | 6 | A | M | 3 |
| | | A | W | 3 |
| | | B | F | 3 |

A = 50 x 50 x 10mm, B = 250 x 250 x 10mm, M = Moisture Content, W = Water Absorption, F = Flexural Strength

The properties of the fiber-mortar composite plates were experimentally investigated. The main variables were the fiber type and the fiber content expressed in terms of the number of fiber mesh layers. The fiber contents used in the fabrication of the fiber-mortar composite plates were 2-, 4- and 6-layer fiber meshes. From the production of the fiber meshes for reinforcements to the fabrication of the fiber-mortar composites, care was taken to ensure proper and accurate shapes and dimensions of the composites to be used as test specimens. All test specimens were cured under the same environmental conditions for 28 days before testing so as to have more reliable results. Tests were performed to determine the flexural strengths expressed in terms of modulus of rupture of the composite plates. Other relevant properties obtained from these tests were the modulus of resilience and modulus of toughness of the plates.

## Moisture Content

The moisture content of the plates was conducted using the 50 x 50 x 10mm specimens. The specimens were weighed before being placed in the oven at a temperature of 105°C for 24 hours. The weights of the oven-dried specimens were recorded after cooling at room temperature. The ratio of the difference between natural and oven-dried weights to the oven-dried weight expressed as a percent is the moisture content of the plate.

### Water Absorption

The water absorption of the plates was measured using the 50 x 50 x 10mm specimens. The specimens were immersed horizontally in water for 24 hours. After the 24-hour immersion, the specimens were taken out and allowed to drain for 10 minutes. Subsequently, the excessive water was wiped off with an absorbent cloth so as to achieve a saturated surface-dried condition after which the specimens' weights were measured and recorded. The specimens were then kept in the oven at a temperature of 105°C for 24 hours. The specimens from the oven were then cooled at room temperature and then the weights were taken and recorded. The water absorption of the plate is the ratio of the difference in weight between the saturated surface-dried weight and the oven-dried weight to the oven-dried weight expressed as a percent.

### Flexural Strength

The 250 x 100 x 10mm specimens were used to measure the flexural strength of the plates. The specimen was supported over a span of 225mm and subjected to third-point loads until failure. The flexural strength was expressed in terms of modulus of rupture. Other relevant properties determined from the flexural strengths were the modulus of resilience and modulus of toughness. American Concrete Institute (ACI) [14] defines modulus of rupture as a measure of the ultimate load-carrying capacity of a material. ACI defines toughness as the capacity of a material to absorb energy during the application of load to fracture. It is said to be dependent on both strength and ductility. The modulus of toughness is expressed in terms of the work performed in deforming a material to fracture.

## Test Results

### Moisture Content and Water Absorption

The moisture content and water absorption of the plain mortar plates were increased with the addition of abaca and sisal fibers, as shown in Tables 2 and 3, respectively. It was found that the moisture content and water absorption of the abaca and sisal fiber-mortar composite plates were directly proportional to the fiber content. As to the type of reinforcement, it was found that the composites with abaca fibers showed higher moisture content and water absorption than those containing sisal fibers in all cases.

**Table 2. Average Moisture Content of Plates**

**Table 3. Average Water Absorption of Plates**

| **Type of Fiber Reinforcement** | **Moisture Content (%) , at Number of Fiber Mesh Layers** | | | |
|---|---|---|---|---|
| | **0 layer (control)** | **2 layers** | **4 layers** | **6 layers** |
| Abaca | | 6.44 | 6.92 | 7.66 |
| | 6.06 | | | |
| Sisal | | 6.32 | 6.80 | 7.50 |

| **Type of Fiber Reinforcement** | **Water Absorption (%) , at Number of Fiber Mesh Layers** | | | |
|---|---|---|---|---|
| | **0 layer (control)** | **2 layers** | **4 layers** | **6 layers** |
| Abaca | | 8.72 | 8.90 | 9.24 |
| | 7.74 | | | |
| Sisal | | 8.51 | 8.75 | 9.15 |

### Modulus of Rupture

There were marked improvements in the moduli of rupture of the plain mortar plates in the presence of abaca and sisal fibers; abaca being more effective than sisal. The plates reinforced with 2-, 4- and 6-layer abaca fiber meshes were observed to produce moduli of rupture about 60%, 72% and 85%, respectively, higher than that of the plain mortar plates. On the other hand, the plates reinforced with 2-, 4- and 6-layer sisal fiber meshes were observed to produce moduli of rupture about 54%, 65% and 74%, respectively, higher than that of the plain mortar plates. The average moduli of rupture of the plates obtained from the tests are shown in Table 4. It can be seen from the test data that for all cases, the moduli of rupture increased with the increase in fiber content.

**Table 4. Average Modulus of Rupture of Plates**

| **Type of Fiber Reinforcement** | **Modulus of Rupture (MPa) , at Number of Fiber Mesh Layers** | | | |
|---|---|---|---|---|
| | **0 layer (control)** | **2 layers** | **4 layers** | **6 layers** |
| Abaca | | 8.625 | 9.300 | 9.975 |
| | 5.400 | | | |
| Sisal | | 8.325 | 8.925 | 9.375 |

## Modulus of Resilience

The amount of energy recovered per unit volume of a material when it is stressed to its elastic limit and then the stress is relieved, is the elastic resilience of the material. Table 5 shows the average moduli of resilience of the fiber-mortar composite plates. The increases in the moduli of resilience of the plain mortar plates were about 68%, 64% and 50% with the addition of 2-, 4- and 6-layer abaca fiber meshes, respectively. In the case of 2-, 4- and 6-layer sisal fiber meshes, the increases in the moduli of resilience of the plain mortar plates were about 59%, 55% and 45%, respectively. From the test results, it was observed that the moduli of resilience of the fiber-reinforced plates decreased as the fiber contents increased. It was also evident from the results that the abaca fiber-mortar composites have higher moduli of resilience than the sisal fiber-mortar composites.

**Table 5. Average Modulus of Resilience of Plates**

| Type of Fiber Reinforcement | Modulus of Resilience (N-m) , at Number of Fiber Mesh Layers | | | |
|---|---|---|---|---|
| | 0 layer (control) | 2 layers | 4 layers | 6 layers |
| Abaca | | 0.037 | 0.036 | 0.033 |
| | 0.022 | | | |
| Sisal | | 0.035 | 0.034 | 0.032 |

## Modulus of Toughness

The average moduli of toughness of the fiber-mortar composite plates are shown in Table 6. Results show significant increases in the moduli of toughness of the plain mortar plates and were obtained with the addition of abaca and sisal fibers. The fiber-mortar composite plates containing 2-, 4- and 6-layer abaca fiber meshes have shown increases in the moduli of toughness of 263%, 339% and 400%, respectively. Likewise, composites containing 2-, 4- and 6-layer sisal fiber meshes have shown increases in the moduli of toughness of 235%, 288% and 353%, respectively. Results have shown that the moduli of toughness were significantly improved with the increase in fiber content. This is a demonstration of high ductility imparted by low modulus fibers like abaca and sisal fibers. It has also been found that composites with abaca fiber reinforcements have higher moduli of toughness than those with sisal fiber reinforcement.

| Type of Fiber Reinforcement | Modulus of Toughness (N-m) , at Number of Fiber Mesh Layers | | | |
|---|---|---|---|---|
| | 0 layer (control) | 2 layers | 4 layers | 6 layers |
| Abaca | | 0.178 | 0.215 | 0.245 |
| | 0.049 | | | |
| Sisal | | 0.164 | 0.190 | 0.222 |

**Table 6. Average Modulus of Toughness of Plates**

## Conclusion

An experimental study was conducted to assess the properties of natural cellulose fibers—namely, abaca and sisal—and cement-mortar composites reinforced with these fibers. The study looked into the effects of fiber addition in the form of meshes on the performance of these natural fiber-reinforced cement-mortar composites.

The moduli of rupture of the plain mortar plates increased by about 54% – 85% with the addition of abaca and sisal fibers. The increases in the moduli of resilience of the plain mortar plates with the addition of abaca and sisal fibers were about 45% – 68%. The moduli of toughness of the plain mortar plates were significantly improved (about 235% – 400%) with the addition of abaca and sisal fibers. For all cases, plate properties were increased more with the addition of abaca fibers than with sisal fibers. The values of the moduli of rupture and moduli of toughness increased with the increase in fiber content, while the values of the moduli of resilience decreased with the increase of fiber content.

This study found that the use of natural organic fiber meshes as reinforcements in cement-mortar matrices considerably improved the overall performance of the plain mortar plates. Hence, such fiber reinforcements possess very good potential for use as reinforcements in cement-based materials.

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# Biography

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