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Modeling the Mechanical Behavior of a Cement Mortar Based on Plant Fibers

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Abstract: Today, technological progress demands the use of innovative materials that offer superior thermal and acoustic properties alongside high mechanical performance, all while maintaining economic competitiveness. This need has driven researchers to create a new generation of advanced materials. In Algeria, building facades are primarily made of bricks, which add to the structural weight, prolongs construction time, and offers insufficient thermal and acoustic insulation. The objective of this experimental modeling is to design a new material incorporating plant fibers. This experimental study aims to examine the effect of sisal fiber slenderness by using two different fiber lengths (7cm and 3cm). Various fiber percentages were tested: 0%, 0.25%, 0.5%, 0.75%, 1%, 1.25%, and 1.5%. After 28 days of curing, mechanical performance was evaluated through compression tests on 4×4×4 cm^3 specimens and three-point bending tests on 4×4×16 cm^3 specimens. The best variant will be used for manufacturing multi-layer panels. The results showed that fiber-reinforced mortars exhibited higher strength compared to the control mortar.

Keywords: Sisal fiber, Mortar, Valorization, Mechanical tests

Introduction

For centuries, humans have sought to improve the strength of fragile construction materials by incorporating various types of fibers. Well-known historical examples include clay bricks reinforced with straw (Achour, 2017), lime mortars mixed with animal hair, and plasters combined with tow (flax fibers). Over time, a wide range of fibers has been experimented with, including glass, steel, plastic, and carbon fibers, as well as plant-based fibers (Ponce-Antón et al., 2024; Ascione et al., 2024)

Nowadays, research has shifted toward more environmentally friendly solutions in response to current sustainable development challenges (Duffy, 2009). As a result, plant-based fibers, mainly derived from agricultural and forestry sectors, have emerged as a potential alternative to conventional fibers such as glass and

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carbon. Lightweight, renewable, low-cost, and offering acceptable mechanical strength, these fibers present numerous advantages. Due to the low fiber consumption in many developing countries, it is possible to achieve reduced energy and technological impact (Dufresne, 2003; Elfaleh et al., 2023; Dallel, 2012).

From a technical perspective, plant-based fibers possess a porous structure that grants them excellent thermal and acoustic insulation properties (Dallel, 2013; Shinoj et al., 2010). Their flexibility also facilitates implementation, particularly when the incorporation rate within the matrix is high. In contrast to metallic fibers, such as steel, they are easier to handle and integrate into materials. These characteristics make natural fibers key components in a new generation of sustainable, lightweight, and cost-effective materials (Yousif & Shallwan, 2013; Habibi et al., 2020). Sisal fiber, extracted from the leaves of *Agave sisalana*, is one of the most widely used natural fibers in the world (Bessell, 1982). It originates from the tropical and subtropical regions of North and South America (Ramamoorthy et al., 2015). Each sisal plant has approximately 200 to 250 leaves, each containing 1,000 to 1,200 bundles, with an average length of 3 mm per elementary fiber (Sanjay et al., 2016; Ramesh et al.,2017). Easy to cultivate, it is produced on a large scale, and its use continues to grow due to its versatility. Rich in cellulose, it exhibits good mechanical strength, particularly in tension (Baley et al., 2005; Bongarde et al., 2014), while having a low moisture absorption capacity, which makes it especially suitable for construction materials (Savastano Jr et al., 2000; Dufresne et al., 2003).

The study presented is part of an ecological approach. Its objective is to develop a construction material that combines lightness with sufficient mechanical strength, primarily for wall insulation applications. The aim is twofold: to improve the thermal and acoustic performance of structures while maintaining acceptable structural integrity. To this end, the influence of sisal fiber fineness was examined by testing two lengths: 3 cm and 7 cm. Several incorporation rates were evaluated: 0%, 0.25%, 0.5%, 0.75%, 1%, 1.25%, and 1.5%. After a 28-day curing period, the mechanical strength of the samples was assessed through three-point bending tests on specimens measuring 4×4×16 cm³. The results showed a significant improvement in the mechanical performance of fiber-reinforced mortars compared to the reference mortar. Among the various configurations tested, the mortar containing 1% sisal fibers exhibited the best results, demonstrating the effectiveness of this natural reinforcement in optimizing construction materials

Experimental Analysis

Materials Used

Only one variety of cement mortar was utilized in producing the various specimens.

Cement

The cement used is a Portland cement of class CEM I 42.5R. Its chemical composition and physical properties are presented in Tables 1 and 2.

Table 1. Chemical composition of cement

SiO2	22
Al2 O3	5.5
Fe2O3	3
CaO	64.5
MgO	1.7
SO3	1.9
Na2O et K2O	0.2-1.3
Cl-	0.02
PAF	< 1.5

Table 2. Physical properties of cement

Physical characteristic	Value
Apparent density (kg/m^3)	1130
Absolute density (kg/m^3)	3100
Specific surface (cm^2/g)	3917
Normal consistency(%)	27.48

The Sand

Granular class 0/3 sand sourced from a sand pit in the Tizi-Ouzou region was used, and tap water was employed as the mixing water. To identify the sand, characterization tests were conducted, with all results presented in Table 3.

Table 3. Characteristics of sand

Gravel	Apparent density(g/cm^3) NF P 18-554	Absolute density (g/cm^3) NF P 18-555	Fineness module MF NF P 18-101	Sand equivalent (%) NFP18-598
Sand 0/3	1,485	2,63	2,87	79.25

Sisal Fiber

Natural sisal fibers were used to reinforce the mortar matrix, with their characteristics and the amounts incorporated presented in Tables 4 and 5.

Table 4. Property of sisal fiber

Width or diameter	50-300
Density (kgm^{-3})	1450
Cellulose / lignin content (%)	67/12
Module E (GNm^{-2})	9.4-22
Tensile strength (MNm^{-2})	530-640
Élongation (%)	3-7

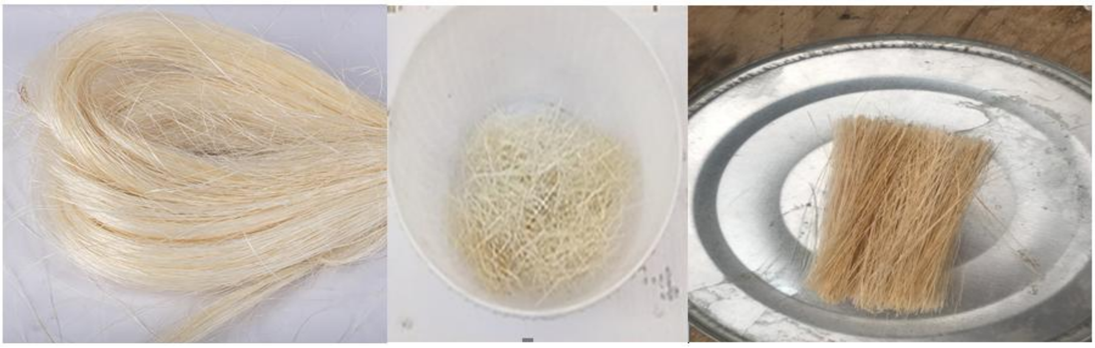

Figure 1. a) Sisal fiber, b) length sisal fiber 3cm, c) length sisal fiber 7cm.

Mix Proportions

Our specimens were prepared using a single composition. After 24 hours, the samples were removed from the molds and kept submerged in a water basin. The proportions of the various constituents are shown in Table 5 and the table.

Table 5. Mortar composition ($1m^3$).

Components	Quantities (Kg)
Cement	450
Sand	1350
Water (L)	225
W/C	0.5

Table 6. Sisal fiber quantities (length 3 and 7cm)

Percentage (%)	0.25	0.5	0.75	1	1.25	1.5
Sisal fibers (g)	0.96	1.92	2.88	3.84	4.8	5.76

Figure 2. Experimental procedure.

Behavior in Three-Point Bending

Bending tests are carried out on specimens of dimensions (4×4×16) cm^3 according to standard NF T 54-606.


Figure 3. Bending test

This table provides the mechanical flexural strength results of the fiber-reinforced mortars and the control mortar, assessed under two different fiber size configurations.

Table 7. Flexural strength of the mortars studied

	Flexural strength (MPa)						
% / Mortar	MT	0.25	0.5	0.75	1	1.25	1.5
MFS3	7.2	7.26	7.05	7.30	7.25	6.95	7.45
MFS7	7.2	7.53	7.37	7.34	8.11	7.99	7.92

MFS3: Sisal fiber mortar with a fiber length of 3 cm.
MFS7: Sisal fiber mortar with a fiber length of 7 cm.

Figure 4 shows the evolution of the flexural strengths of unreinforced and sisal fiber reinforced mortars using two fiber lengths (MFS3) and (MFS7).

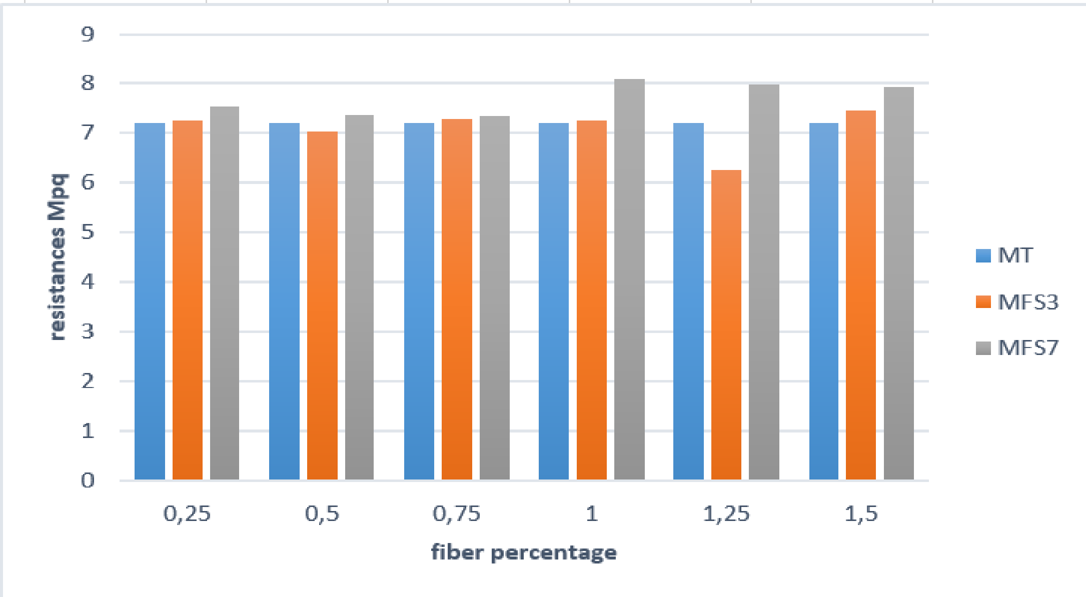

Figure 4. Three-point bending strength of the mortars studied.

According to the figure above, the incorporation of 7 cm sisal fibers significantly enhances the flexural strength of the mortar compared to the control. The optimal performance is observed at a 1% fiber dosage. A moderate increase in strength is also noted for mortars reinforced with 3 cm fibers.

Influence of Fiber Length

In this section, the influence of the length of Sisal fibers in the different mortars is presented and analyzed in Figure 5.

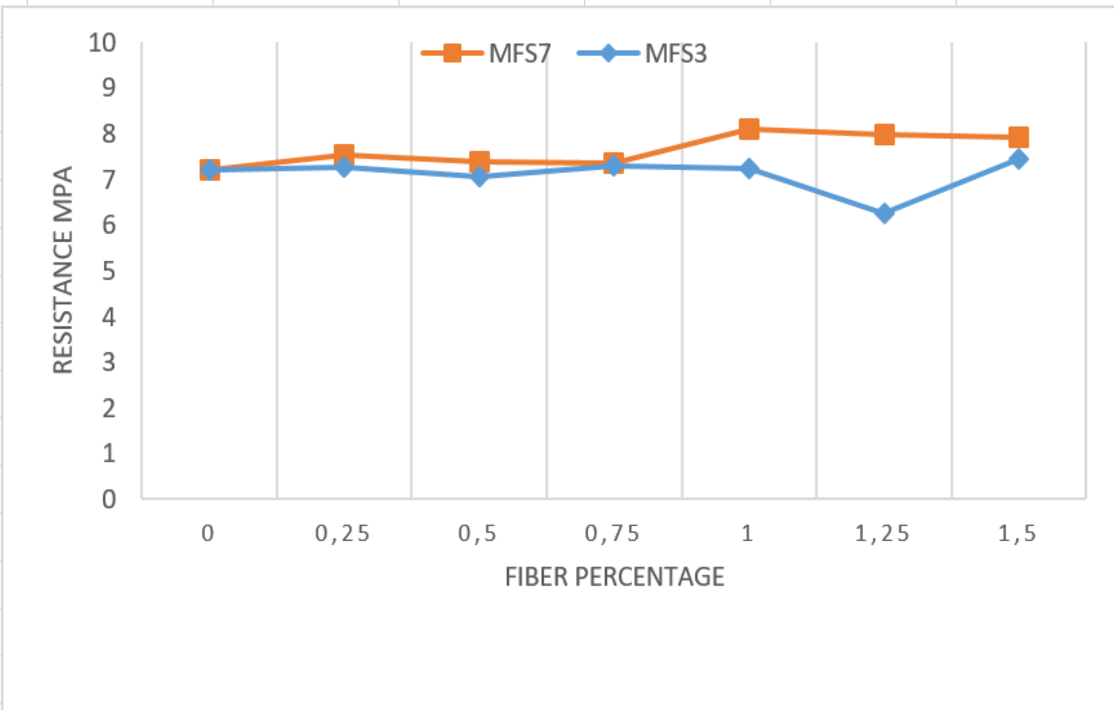

Figure 5. Influence of fiber length

The MFS7 mortar exhibited superior post-peak behavior compared to other formulations, particularly MFS3, highlighting the significant influence of fiber length on flexural strength. Indeed, MFS7 achieved a maximum strength of 8.11 MPa, compared to 7.25 MPa for MFS3, representing an 11% increase. For comparison, the control mortar recorded a strength of 7.2 MPa. The incorporation of 7 cm fibers enhances the cohesion of the mortar by limiting the initiation, propagation, and widening of cracks through a bridging effect, thereby optimizing its strength and durability.

Conclusion

Based on the results obtained in this experimental investigation, we were able to draw the following conclusions:

- The length parameter of the Sisal fibers influences the resistance of these mortars.
- The maximum tensile strength by bending is higher for mortars with 7 cm long fibers than for the reference mortar (without fibers).
- The mortars with fibers 7 cm in length presented better performances, in tractions by bending, compared to the mortar of fibers of 3 cm. There is a difference of 11%.
- The best resistances for the 7 cm fiber are recorded for a dosage of 1%, on the other hand for the 3 cm fiber the best performance is recorded for a dosage of 1.5%.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

Conflict of Interest

* The authors declare that they have no conflicts of interest

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