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Effect of Doum and Polypropylene Fibres on the Physical and Thermomechanical Properties of Stabilized Earth Blocks (SEBs)

Othmane Nouari [1,2], Mohamed Rabehi [2,*], Said Zaouai [2]
[1] *Built Environmental Research Laboratory, Civil Engineering Faculty, Sciences and Technology Department, University of Houari Boumediene, Algeria*
[2] *Civil Engineering and Sustainable DevelopmentLaboratory, Faculty of Sciences and Technology, Ziane Achour University of Djelfa, 17000 Djelfa, Algeria.*
** rabehi_moh@univ-djelfa.dz*
https://orcid.org/my-orcid?orcid=0000-0002-3094-1720

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ABSTRACT

Earth-based materials are increasingly recognized as sustainable and low-energy alternatives to conventional construction materials. However, stabilized earth blocks (SEBs) often suffer from low tensile strength and limited durability, which restrict their structural applications. Fibre reinforcement has proven to be one of the most effective methods to enhance their mechanical and thermal performance. This research investigates the combined effect of Doum fibre (DF) and Polypropylene (PPF) fibres on the physical and thermomechanical properties of stabilized earth blocks (SEBs) produced from local Algerian soils. The mix design consisted of 70% soil, 20% dune sand, and 10% cement, while Fibre content was varied at 0.1%, 0.2%, 0.3%, 0.4%, and 0.5% for both Doum fibre (DF) and Polypropylene (PPF). The blocks were compacted under a pressure of 2 MPa and cured for 28 days under controlled laboratory conditions. The results reveal that fiber inclusion significantly alters SEB performance, with optimal improvements observed at 0.4% for DF and 0.3% for PPF. While PPF-enhanced SEBs consistently demonstrated superior mechanical properties—such as higher compressive and tensile strength, and UPV—DF-reinforced SEBs exhibited better thermal conductivity. These findings highlight the potential of fiber-reinforced SEBs for sustainable construction, with fiber type and dosage playing a critical role in tailoring material performance to specific functional requirements.

Keywords: Stabilized earth blocks, Doum fibre, Polypropylene fibre, Mechanical properties, Thermal performance, Sustainable construction.

INTRODUCTION

The construction sector plays a crucial role in Algeria's socio-economic development but also contributes significantly to environmental degradation due to high energy consumption and CO_2 emissions from the production of conventional materials such as cement and fired bricks. In response to these challenges, stabilized earth blocks (SEBs) have gained attention as eco-friendly and affordable alternatives. [1-4] These blocks are produced from local soils stabilized with binders such as cement or lime, offering low embodied energy and a reduced carbon footprint. [5-9].

Algeria's geographical diversity—from the humid Mediterranean north to the arid Saharan south—presents diverse climatic constraints and building requirements. The country's vast availability of clayey and silty soils makes it particularly well-suited for developing earth-based construction materials that are both economically viable and climatically adapte. [10-12].

Among natural fibres, Doum fibre—extracted from the palm *Hyphaene thebaica*—offers great potential for sustainable construction. It is abundant in southern Algeria, biodegradable, low-cost, and provides good adhesion with the soil matrix after alkaline treatment. Studies by Essabir et al. (2013) demonstrated that Doum fibre reinforcement significantly improved the tensile and thermal properties of polymer composites. The use of this local natural fibre can therefore contribute both to the improvement of SEB performance and to the valorization of regional resources, generating economic benefits and supporting rural employment [13].

n addition to natural fibres, synthetic fibres, particularly Polypropylene (PP), have been widely employed in construction due to their excellent chemical stability, high tensile strength, and low cost. PP fibres enhance the mechanical integrity of cementitious and soil-based materials by increasing their ductility, tensile strength, and crack resistance. Studies by Boulekbache et al. (2011) and others demonstrated that PP fibre incorporation improved the post-cracking behaviour and durability of reinforced concrete composites [14]. Furthermore, PP fibres are hydrophobic, lightweight, and resistant to alkalis, making them suitable for humid or saline environments often encountered in coastal and southern Algerian regions. When incorporated into cementitious or soil matrices, PP fibres help control microcracking and improve both compressive and flexural performance [15].

Despite numerous studies on individual fibre types [10-12], limited research has examined the combined influence of Doum and Polypropylene fibres on the mechanical and thermal performance of stabilized earth blocks, particularly under Algerian climatic and soil conditions.

Therefore, the objective of this research is to evaluate the effects of Doum and polypropylene (PP) Fibres, incorporated at varying contents (0.1%, 0.2%, 0.3%, 0.4%, and 0.5%), on the density, open porosity, compressive strength, flexural strength, and thermal conductivity of stabilized earth blocks (SEBs) containing 10% cement. The aim is to identify optimal combinations that enhance performance while ensuring both economic feasibility and environmental sustainability.

MATERIALS AND METHODS

1.1.Raw Materials

The clayey soil used in this research was collected from the Tissemsilt region in north-central Algeria. This area provides abundant deposits of fine-grained soil suitable for earthen construction the Chemical composition of soil and sand used and properties of Characteristics of clayused are shown in **Table 1**, **Table 2**. Ordinary Portland cement CEM II/B class 42.5 according to EN 197–1 conforming to EN 197-1 was used as the stabilizing agent. The cement content was varied at 6%, 8%, 10%, and 12% by weight of dry soil to evaluate its influence on strength and thermal performance. The selection of these percentages aimed to cover the typical range used in stabilized earth block production while ensuring economic feasibility. River sand from Tissmsilite (Algeria) was used to modify the fines proportion of the soil. The Physical and mechanical properties of sand used are shown in **Table 3**.

Two types of fibres were used in this study (**Figure. 1**): Doum fibre (Hyphaene thebaica) and Polypropylene (PP) fibre.

- The **Doum Fibres** (DF) were extracted from the outer layers of the Doum palm available in southern Algeria. The fibres were manually cleaned, washed, and treated with a 5% NaOH

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solution for 4 hours to remove surface impurities and enhance adhesion with the cementitious matrix. After treatment, the Fibres were rinsed with distilled water and air-dried. The average fibre length was **30 ± 5 mm** and the diameter ranged from **0.3 to 0.6 mm**; tensile strength is approximately **55 MPa;** density of **1.38 g/cm³**.

- The **Polypropylene Fibres** (PPF) were commercially obtained, with an average length of **12 mm**, tensile strength of **400 MPa**, and density of **0.91 g/cm³**. They were used as received without further treatment.

Figure 1. Types of Fibres used; (a) Doum Fibres (DF), (b) Polypropylene Fibres (PPF)

Table 1. Chemical composition of soil and sand used

Type	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	Zno	P_2O_5
Clay	55.26	6.40	4.99	13.95	1.63	0.15	1.59	0.33	0.010	0.020
Sand	88.05	0.77	0.28	4.62	0.19	0.05	0.43	0.01	0.020	0.010

Table 2. Characteristics of soil

Apparent volumetric mass	Absolute density	PH
1.23 g/cm3	2.33 g/cm3	7.90

Table 3. Physical and mechanical properties of sand.

Property	(0/5)
Apparent volume mass (g/cm3)	1.350
Absolute density mass (g/cm3)	2.54
Sand equivalent (%)	92.0
Fineness modulus	2.34
Degree of absorption (%)	0.31

1.2. Block Fabrication and Curing

The mix components (soil, cement, and fibres) (see Figure 2) were thoroughly mixed before adding water. The mixture was compacted into steel moulds (200 × 100 × 100 mm) under a pressure of 2 MPa. The blocks were cured for 28 days under controlled laboratory conditions (20°C±2, 70% RH).

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Figure 2. Block Fabrication and Curing

A comprehensive experimental **program was conducted to evaluate the physical, mechanical, and thermal properties of the stabilized earth blocks reinforced** with Doum and Polypropylene (PP) fibres. The following tests were performed after 28 days of curing (see Figure 3):

- The apparent (bulk) density of the specimens was determined in accordance with ASTM C642. [17]
- The capillary water absorption test is commonly conducted according to ASTM C1585. [18]
- The Compressive strength of the specimens was determined in accordance with according to ASTM C109. The load was applied at a constant rate of 0.5 MPa/s until failure. The average of three specimens per mixture was recorded as the representative value. [19]
- The Tensile strength was determined using ASTM C78.
- The Ultrasonic Pulse Velocity (UPV) test was conducted in accordance with ASTM C597 to evaluate the homogeneity and internal quality of the blocks. [20]
- Thermal conductivity was measured using the steady-state heat flow method in accordance with ASTM C518. Specimens were dried to constant mass at 105 °C before testing. [21] The thermal conductivity coefficient (λ) was recorded in W/m·K, and results were averaged from three replicates for each composition.

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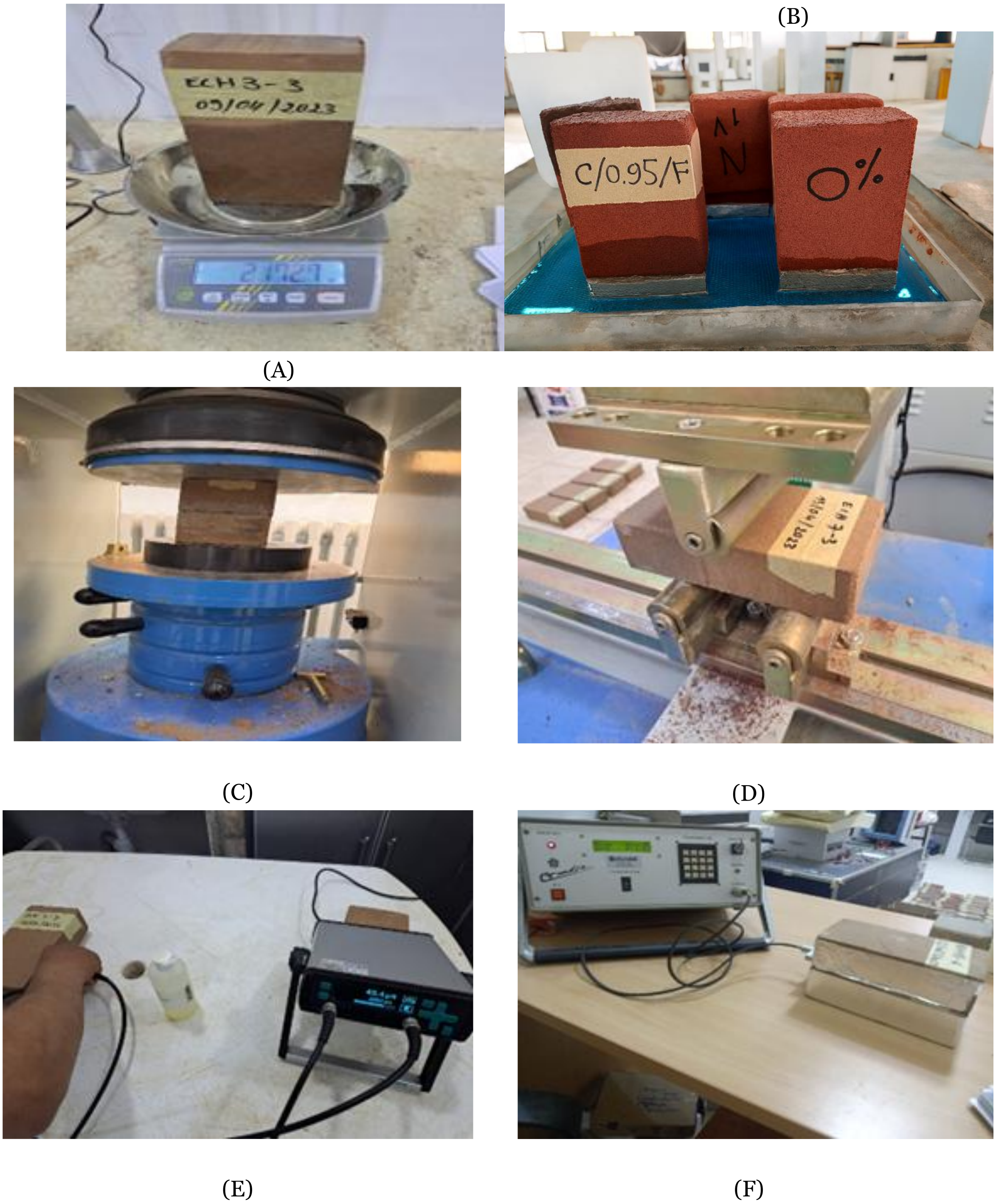

Figure 3. Testing Methods: **(A)** Apparent (bulk) density of the specimens, **(B)** Capillary water absorption test, **(C)** Compressive strength test, **(D)** Tensile strength test, **(E)** Ultrasonic Pulse Velocity (UPV) test, **(F)** Thermal conductivity test.

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RESULTS AND DISCUSSION

1.3. Density

Figure. 4 illustrate a consistent decline in the density of Fibre-reinforced stabilized earth blocks (SEBs) as the Fibre content increases, regardless of Fibre type. This trend is primarily attributed to the reduction in the average unit weight of the solid constituents within the SEBs matrix. the results further confirm that the incorporation of Fibres leads to a lower maximum density, mainly due to the relatively low density of the added inclusions. Several factors explain this reduction in density: Lower specific gravity of the Fibres compared to soil particles. In this study, the dry densities of soil, dune sand, doum Fibres (DF) and Polypropylene Fibres (PPF) were 2.33 g/cm³, 2.65 g/cm³, 1.38 g/cm³, and 0.90 g/cm³, respectively; Increased compaction efficiency resulting from the flexibility of doum and Polypropylene (PP) Fibres, which facilitates particle rearrangement and reduces the overall density of the soil-Fibre composite; Reduced optimum moisture content due to the limited water absorption capacity of doum and Polypropylene (PP) Fibres compared to soil, which affects the compaction behavior and moisture retention of the mixture.

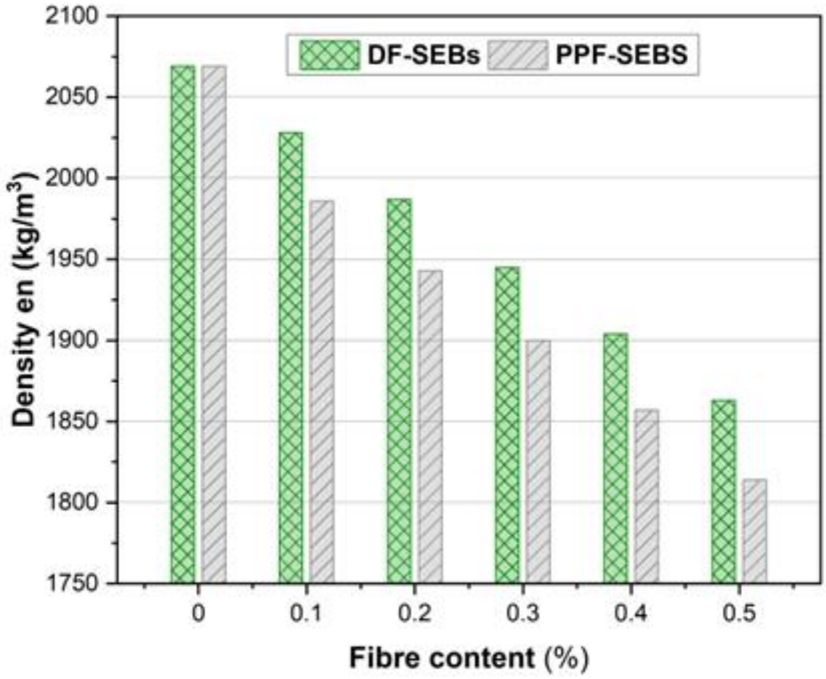

Figure. 4. Effect of doum Fibres (DF) and Polypropylene Fibres (PPF) on the density.

For example, increasing the content of doum Fibres (DF) and Polypropylene Fibres (PPF) from 0.1% to 0.5% led to a reduction in density by 8.13% and 8.66%, respectively. These findings indicate that Doum Fibres -reinforced SEBs exhibit higher density than those reinforced with Polypropylene (PP) Fibres, primarily due to the lighter nature of Polypropylene (PP) Fibres compared to doum Fibres. The results demonstrate that Fibre incorporation contributes to a reduction in maximum density, primarily due to the lower density of the added inclusions, as observed in other studies [22].

1.4.Open porosity of SEBS

The open porosity (ε) represents the ratio between the void volume (Vvoid) and the total volume of the material (Vtotal). This parameter is critical for characterizing the internal structure of porous materials and assessing their fluid transport behavior. In particular, it enables the quantification of the relationship between the amount of water absorbed per unit surface area (Δm/A) and the vertical progression of the liquid front (Hfrontal), which are key indicators of capillary action and moisture ingress in cement-stabilized earth blocks. Where it is calculated by Eq. 1:

$$\varepsilon(\%) = (V_{Void} \,/\, V_{Total}).100\% = ((\Delta m \,/A)\ .100\%)/(\rho w{\cdot}H_{frontal}) \qquad (1)$$

where ε is the open porosity, expressed as a percentage; (Δm/A) is the water absorption rate per surface area, measured in kilograms per square meter per square root hour; ρw is the density of water, equivalent to 1 gram per cubic centimeter or 1000 kilograms per cubic meter; Hfrontal is the height reached by water through capillary action, set at 5 centimeters.

1.4.1. Effect of doum Fibres (DF) and Polypropylene Fibres (PPF) on the Open porosity (ε) of SEBS

The results of **Figure.5** indicates that the open porosity (ε) of SEBs decreases progressively with increasing fiber content for both Doum and Polypropylene (PP) fibers, reaching a minimum at 0.4% for Doum fibers and 0.3% for PP fibers. Beyond these optimal levels, the porosity begins to rise gradually.

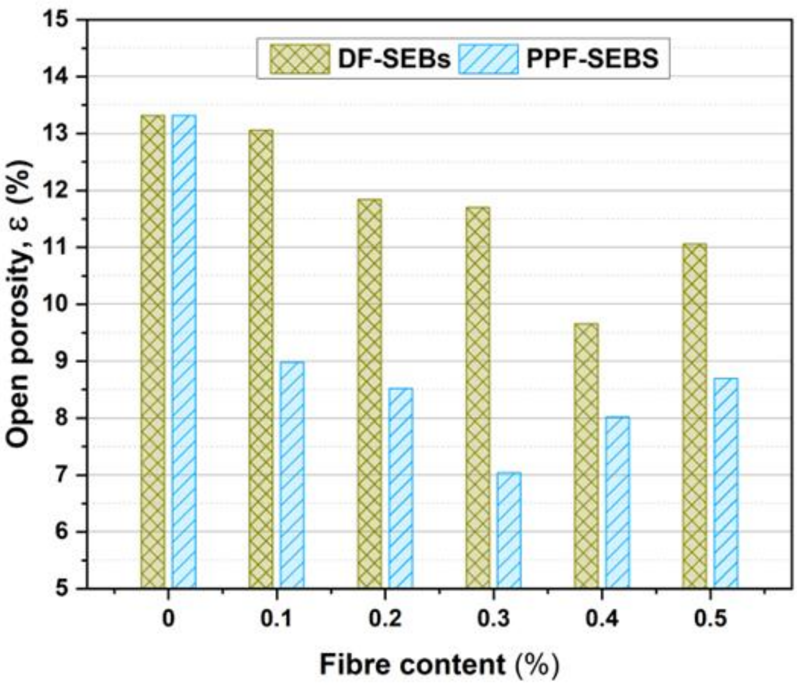

Figure. 5. Effect of doum Fibres (DF) and Polypropylene Fibres (PPF) on the Open porosity (ε) of SEBS.

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For example, increasing the content of Doum fibers (DF) from 0.1% to 0.4% in SEBs resulted in a 26.03% reduction in open porosity (ε). Similarly, raising the proportion of Polypropylene fibers (PPF) from 0.1% to 0.3% led to a 21.60% decrease. It was also observed that SEB mixtures reinforced with Doum fibers exhibited higher open porosity values compared to those containing Polypropylene fibers. These findings are consistent with recent research by El-Sayed et al. (2023) [23], which demonstrated that Doum fibers, due to their coarser morphology, tend to retain more voids in composite matrices than synthetic fibers like PP. Comparable results were also reported by Estabragh et al. (2012) [24], who found that the inclusion of glass fibers in soil-cement mixtures improved compressive strength by approximately 30%.

1.5. Compressive strength

1.5.1. Effect of doum Fibres (DF) and Polypropylene Fibres (PPF) on the Compressive strength of SEBS

The results of **Figure. 6** show that the compressive strength for the two types of fiber is increasing according to the increase in the fiber content up to a maximum at 0.4% for the doum fibres (DF) and at 0.3% for the Polypropylene fibers (PPF), and then beyond this optimum it becomes gradually decreasing.

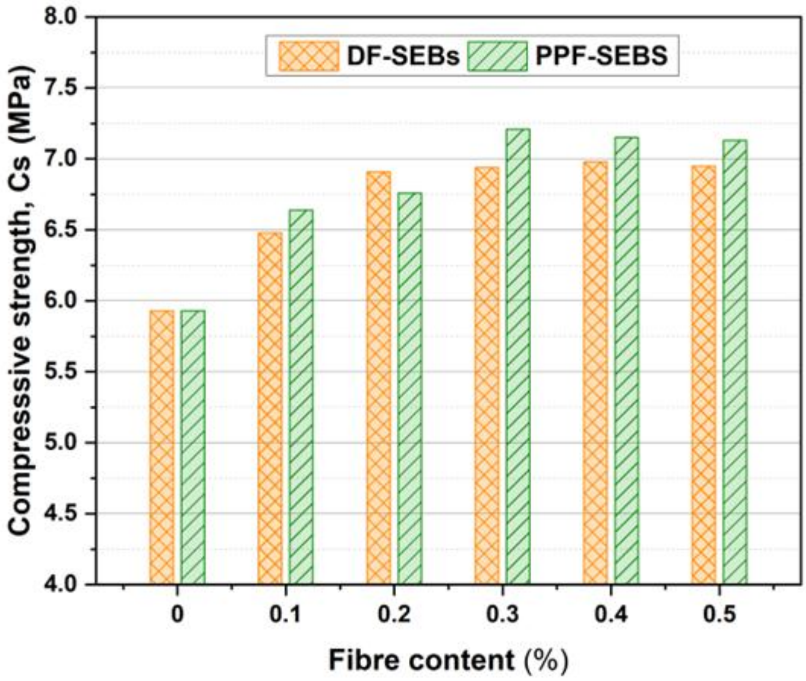

Figure. 6. Effect of doum Fibres (DF) and Polypropylene Fibres (PPF) on Compressive strength, Cs of SEBS.

For example, increasing the content of Doum fibers (DF) from 0.1% to 0.4% in stabilized earth blocks (SEBs) resulted in a 7.72% increase in compressive strength. Similarly, raising the proportion of Polypropylene fibers (PPF) from 0.1% to 0.3% led to an 8.58% improvement. Notably, SEB mixtures reinforced with PPF consistently exhibited higher compressive strength values compared to those containing DF. These findings align with recent studies such as El-Sayed et al.

(2023) [25], which demonstrated that polypropylene fibers enhance mechanical performance due to their uniform dispersion and strong interfacial bonding with the matrix. In contrast, Doum fibers, while beneficial, tend to introduce more variability due to their natural morphology and lower compatibility with cementitious matrices [26].

1.6.Tensile strength

The tensile strength is expressed by the ability of the blocks, to resist the destruction under the action of the stresses due to traction. The results of the tensile test are shown in **Figure. 7.**

1.6.1. Effect of doum Fibres (DF) and Polypropylene Fibres (PPF) on the Tensile strength of SEBS

The results presented in **Figure.** 7 show that the tensile strength of SEBs increases with fiber content, reaching a maximum at 0.4% for Doum fibers (DF) and 0.3% for Polypropylene fibers (PPF). Beyond these optimal levels, the tensile strength gradually decreases.

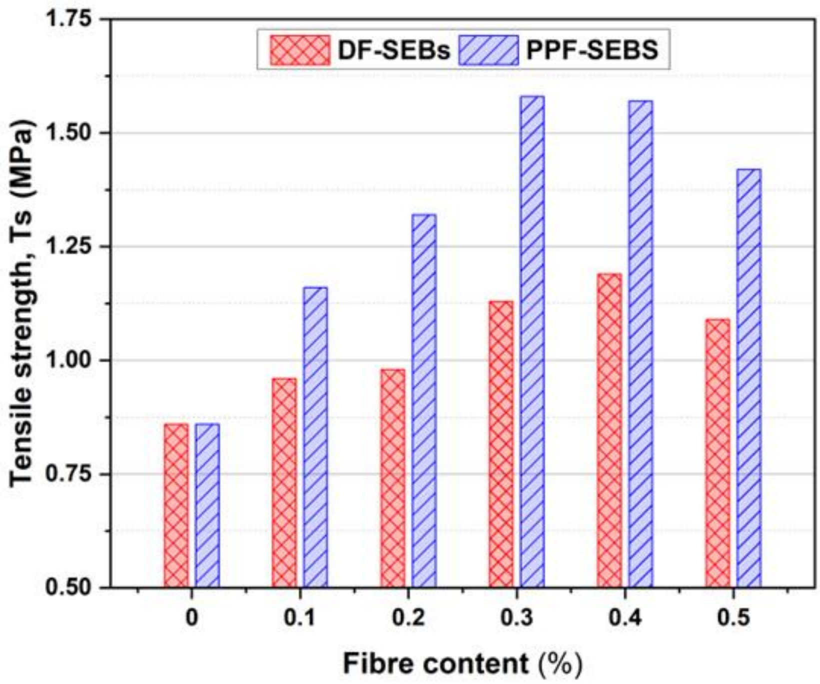

Figure. 7. Effect of doum Fibres (DF) and Polypropylene Fibres (PPF) on Tensile strength, Ts of SEBS.

For example, increasing the Doum fiber (DF) content from 0.1% to 0.4% in SEBs led to a 23.96% improvement in tensile strength. However, further increasing the DF content to 0.5% resulted in an 8.40% reduction. Additionally, SEBs reinforced with Polypropylene fibers (PPF) consistently exhibited higher tensile strength values compared to those containing Doum fibers. These findings suggest that fiber inclusion—particularly with PPF—enhances the tensile performance of SEBs, which aligns with the results reported by El-Sayed et al. (2023) [25], who demonstrated that polypropylene fibers significantly improve mechanical properties due to their uniform dispersion and strong interfacial bonding with the matrix. Similarly, Saber et al. (2022) [27] highlighted that treated natural fibers,

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including Doum, contribute to enhanced tensile behavior, although synthetic fibers like PPF often outperform them in consistency and strength.

1.7. Ultrasonic pulse velocity (UPV)

1.7.1. Effect of doum Fibres (DF) and Polypropylene Fibres (PPF) on the Ultrasonic pulse velocity (UPV) of SEBS

Figure. 8 illustrates that the Ultrasonic Pulse Velocity (UPV) of SEBs increases with the addition of fibers, peaking at 0.4% for Doum fibers (DF) and 0.3% for Polypropylene fibers (PPF). Beyond these optimal contents, the UPV values begin to decline progressively.

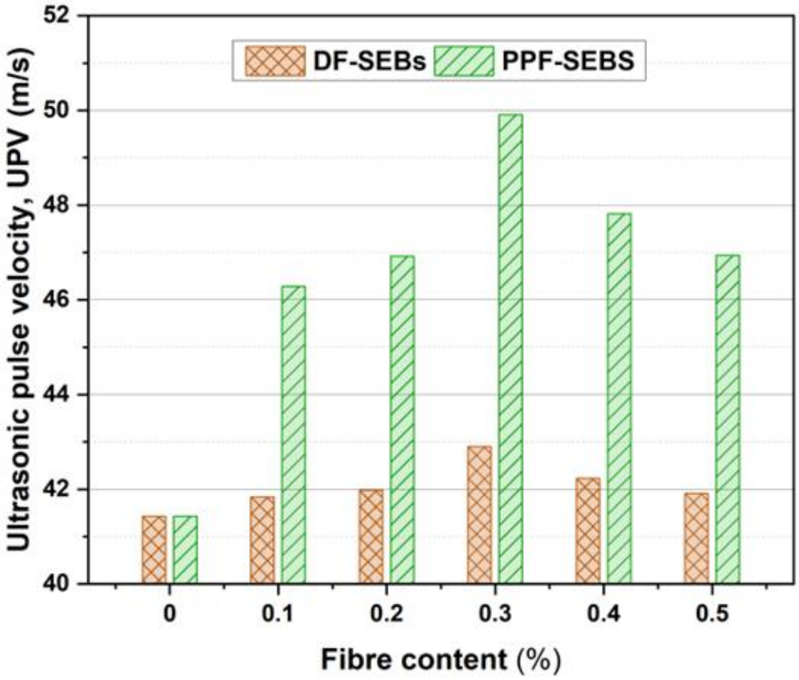

Figure. 8. Effect of doum Fibres (DF) and Polypropylene Fibres (PPF) on Ultrasonic Pulse Velocity, UPV of SEBS

For example, increasing the Doum fiber (DF) content from 0.1% to 0.4% in SEBs resulted in a 0.93% increase in Ultrasonic Pulse Velocity (UPV). In contrast, raising the DF content further to 0.5% led to a 0.76% decline. Moreover, SEBs reinforced with Polypropylene fibers (PPF) consistently demonstrated higher UPV values compared to those containing Doum fibers. These observations indicate that fiber incorporation—particularly with PPF—enhances the UPV performance of SEBs, corroborating findings reported by Hedjazi and Castillo (2022) [28], who showed that polypropylene fiber-reinforced concrete exhibits improved durability and UPV due to enhanced internal cohesion and reduced microcracking. Additionally, studies by Yildiz et al. (2023) [29] confirmed that UPV is a reliable indicator of fiber-reinforced concrete quality, especially when synthetic fibers like PPF are used.

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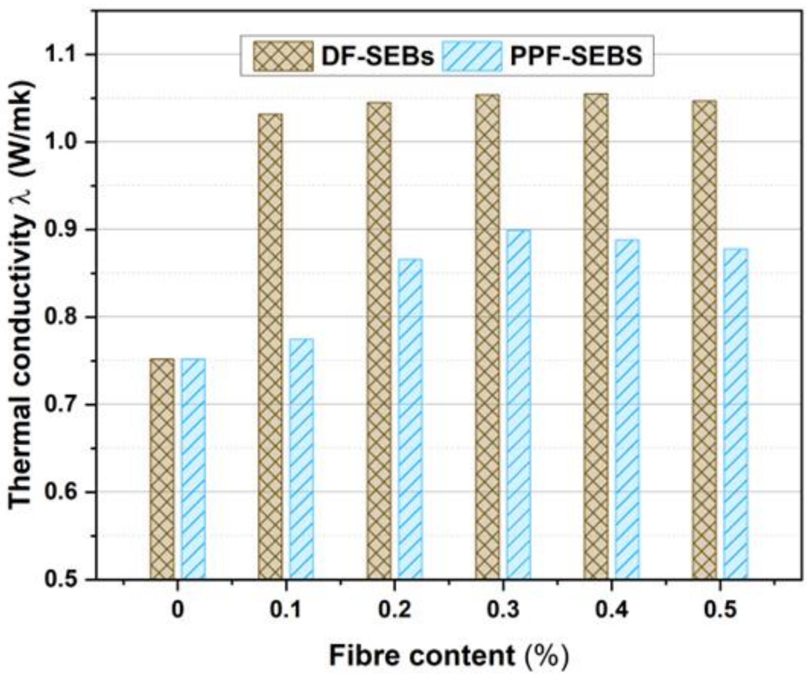
1.8. Thermal conductivity

1.8.1. Effect of doum Fibres (DF) and Polypropylene Fibres (PPF) on on thermal conductivity (λ) of SEBS

Figure. 9 illustrates that the thermal conductivity (λ) of SEBs increases with the addition of fibers, peaking at 0.4% for Doum fibers (DF) and 0.3% for Polypropylene fibers (PPF). Beyond these optimal contents, the thermal conductivity λ values begin to decline progressively.



. **Figure. 9.** Effect of doum Fibres (DF) and Polypropylene Fibres (PPF) on thermal conductivity λ(W/mk) of SEBS

For example, increasing the Doum fiber (DF) content from 0.1% to 0.4% in SEBs resulted in a 2.23% increase in thermal conductivity λ, (W/mK). In contrast, raising the DF content further to 0.5% led to a 0.76% decline. Moreover, SEBs reinforced with Doum fiber consistently demonstrated higher thermal conductivity values compared to those containing Polypropylene fibers (PPF). These observations indicate that fiber incorporation—particularly with Doum fiber—enhances the thermal conductivity performance of SEBs, corroborating findings reported by Elmoudnia et al. (2023) [26], who developed Doum palm fiber-based insulation composites and observed improved thermal behavior. Similarly, El-Sayed et al. (2023) [25] highlighted the influence of Doum fiber morphology and treatment on the thermal properties of polymer composites, confirming its potential for enhancing conductivity.

CONCLUSION

This study confirms that the integration of Doum fibers (DF) and Polypropylene fibers (PPF) has a notable impact on the physical and mechanical behavior of stabilized earth blocks (SEBs). The performance of SEBs across key parameters—density, open porosity, compressive strength, tensile strength, ultrasonic pulse velocity (UPV), and thermal conductivity—is strongly influenced by both the type and proportion of fiber used.

- **Density** consistently decreased as fiber content increased, due to the lower specific gravity of the fibers compared to soil particles. SEBs reinforced with Doum fibers exhibited higher density than those with PPF, reflecting the lighter nature of polypropylene.
- **Open porosity** declined with increasing fiber content up to optimal levels (0.4% for DF and 0.3% for PPF), then began to rise. Mixtures containing Doum fibers showed greater porosity than those with PPF, likely due to the coarse texture and irregular structure of natural fibers.
- **Compressive strength** improved with fiber incorporation, reaching peak values at the same optimal concentrations. SEBs reinforced with PPF consistently achieved higher strength, likely due to superior fiber dispersion and stronger bonding with the matrix.
- **Tensile strength** followed a similar pattern, with PPF outperforming DF. Although Doum fibers contributed to strength gains, their natural variability introduced inconsistencies in performance.
- **Ultrasonic Pulse Velocity (UPV)** increased with fiber content up to the optimum, reflecting enhanced internal cohesion. PPF fibers yielded higher UPV values, indicating improved structural integrity and reduced microcracking.
- **Thermal conductivity** also increased with fiber addition, particularly with Doum fibers, which outperformed PPF in this regard. This is attributed to the denser structure and better thermal transfer properties of DF.

In summary, both fiber types enhance SEB performance, but their effects vary by application. Polypropylene fibers (PPF) are more effective for improving mechanical properties, while Doum fibers (DF) are better suited for enhancing thermal conductivity. These insights support the targeted use of fiber reinforcement in SEBs based on specific functional needs—whether for structural strength or thermal efficiency. Overall, while both fiber types contribute positively to SEB performance, Polypropylene fibers (PPF) offer superior mechanical enhancements, whereas Doum fibers (DF) provide better thermal conductivity. These findings support the strategic use of fiber reinforcement in SEBs, tailored to specific functional requirements—mechanical strength or thermal efficiency.

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