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Physical, Mechanical, and Durability Properties of Compressed Earth Blocks Filled by Juncus Plant Fibers

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ABSTRACT: This paper studies the influence of incorporating Juncus fibers into compressed earth blocks (CEBs). CEB composites were manufactured with earth filled by Juncus fibers reinforcement (0 to 0.8% by weight), and compressed at 10 MPa with a compaction loading press. After 28 days of drying, the CEBs underwent diverse experimental tests to evaluate their physical, mechanical, and durability properties. The findings indicated that incorporating fibers led to a diminution in unit weight, ultrasonic pulse velocity, and dry compressive strength. Despite the drop in mechanical strength, CEBs with higher fiber content (0.4%) demonstrated satisfactory abrasion resistance, which could play a crucial role in areas prone to extreme weather events. According to this experimental investigation, this material has the potential as a promising composite for building materials and reduces the need for chemical stabilizers, which is considered a major contributor to greenhouse gas emissions in the construction industry. The results have implications for affordable housing solutions and offer insightful information about sustainable building materials.

KEYWORDS: compressed earth blocks, Juncus fiber, ultrasonic velocity, compressive strength, abrasion resistance.

1 INTRODUCTION

In recent years, the construction industry has been marked by a general awareness to limit the negative environmental impacts caused by building materials. In this context, the construction industry must adapt its practices to provide innovative materials that meet the new requirements of users and legislation in terms of environmental and health impact, as well as comfort [1]. Building materials reinforced with plant fibers are currently of great interest in this context due to weight gain combined with recommended thermal and mechanical properties.

Plant fibers have significant advantages over synthetic fibers (steel, polymer, and glass fibers) due to their ability to replace them, including reduced reliance on non-renewable energy-material resources, lower pollutant emissions, lower greenhouse gas emissions, enhanced energy recovery, biodegradable behavior, and very interesting specific mechanical properties [2]. However, due to their high absorption capacity, several plant fibers are interesting in terms of sustainable development and are likely to bring additional benefits, such as cracking limitation and material shrinkage reduction [3].

Some studies on materials based on plant fibers have been previously published [4], [5], [6], [7], [8]. Galan-Marin et al. used plant fibers to stabilize soil [9]. Taallah et al. [10] developed date palm fiber-reinforced compressed earth block composite materials. However, while the use of agro-sourced materials is increasing, manufacturing remains largely artisanal. The transition to an industrial and technological phase necessitates process optimization and control (composition, wetting, drying process, mechanical resistances, etc.) [11].

Despite the benefits of plant fiber reinforced composite materials, some degradation issues may arise. These issues were attributed to a combination of fiber weakening caused by alkali attack, fiber mineralization caused by hydration product migration to lumens, and volume variation caused by their high sensitivity to water absorption [6], [12]. Furthermore, the hydrophilic nature of plant materials and their high capacity for water absorption cause a reduction in physical, mechanical, and thermal properties, as well as rotting due to fungi attack. The performance of composites made from plant materials is determined by the matrix, fibers, and interfacial bonding. In composite materials, the adhesion between the reinforcing fibers and the matrix is a limiting factor that affects their mechanical and physical properties.

Several approaches to mitigating these chemical interactions between plant materials and cement hydration have been investigated in previous studies. Gram [13], Ziraba et al. [14], and Canovas et al. [15] investigated the effect of fiber coating and impregnation using blocking and repelling agents (such as epoxy and asphalt). The findings demonstrated some degree of chemical incompatibility reduction. To avoid chemical incompatibility issues, several studies have highlighted the beneficial effect of cement binder partial or total replacement with natural clay [6], [10], [16].

To the best of our knowledge, there are no published works that use Juncus acutus fibers as a reinforcement element to improve certain properties of conventional building materials. As a result, the purpose of this research is to determine the viability of an innovative material made of soil filled by fibers extracted from Juncus acutus (known as Smar in Morocco). The resulting innovative materials are compatible with a context of sustainable development in order to develop renewable natural resources and reduce building material energy consumption.

The purpose of this study was to investigate the potential to use of Juncus acutus fibers as reinforcement additives in soil mixe in order to provide an alternative solution to an environmental problem. Juncus acutus fibers were used as a partial replacement for soil in the mix at various weight levels, including 0% (reference specimen), 0.2%, 0.4%, 0.6%, and 0.8% by weight. The purpose of the experimental-test program was to investigate the properties of hardened samples, such as unit weight, ultrasonic pulse velocity, dry compressive strength, and dry abrasion test.

2 Materials And Experimental Testing

2.1 Materials

2.1.1 Soil

The soil used in this study (Fig. 1) was collected in the Ait ourir region. This soil was chosen because of its availability and abundance and also for its use by local population to manufacture of high-quality earthen buildings materials. This soil's particle size distribution was determined using two techniques: grain size analysis for the coarser fraction greater than 80 m and sedimentary tests for the fine fraction in accordance with NF P94-056 [17] and NM 00-8-083 (2015), respectively.

The plastic limit (WL), plasticity index (PI), and liquid limit (WL) were determined using the Atteberg limit test according to [18]. Its methylene blue value was calculated using NF EN 933-9 [19].

Fig. 1. The soil used in this work

The geotechnical properties of the soil used in this study are shown in Table 1. The soil was constituted of 15% clay, 35% silt, 33.7% sand and 16.3% gravel. The Atterberg limit test indicated that this soil had a liquid limit WL = 30%, plastic limit WP=20% and a plasticity index PI = 10%, which agreed within the recommended zone limit by the French Standards XP P 13-

901 [41]. It had an absolute density of 2300 Kg/$m^{3,}$ and bulk density 1250 Kg/m^3 and a blue methylene value MBV (g/100g) =1.35. Therefore, the soil is in good line with the XP P 13-901 standard for the preparation of compressed earth blocks [41].

Table 1. Geotechnical characteristics of soil

Grain Size Distribution	Atterberg Limits	Methylene Blue Value	Absolute Density
Clay < 2 µm: 15% **Silt (2–63 µm): 35%** **Sand (0.063–2 mm): 33.70%** **Gravel (>2): 16.30%**	Liquid limit, WL = 30% Plastic limit, WP = 20% Plasticity Index, PI = 10%	MBV (g/100 g) = 1.35	2300 Kg/m^3

2.1.2 Juncus Fibers

In this study, Juncus fibers were used. Raw fibers (Fig 2.) were collected from Ourika region located Marrakech Province in Morocco. Before their use in the composite, juncus fibers were washed with water to remove the presence of any impurities. Then, fibers are cut into small pieces with a length ranging between 2 cm and 5 cm. According to Naili et al [21], juncus plant fibers are mainly composed of cellulose (40%), hemicellulose (21%) and lignin 29. Table 2. Summarizes the mechanical properties of juncus plant fiber [22].

Fig. 2. The juncus plant used in this work.

Table 2. Mechanical properties of juncus plant fiber

Fiber	D (µm)	Density(g.cm^{-3})	σ (MPa)	E (GPa)	ε (%)	Ref
Juncus	280 ± 56	1.139	113 ± 36	4.38 ± 1.37	2.75 ± 0.6	[22]

2.2 Sample Preparation

Different compositions of earth blocks samples were produced with different contents of fibers, as shown in Table 3. The preparation of specimens consisted of first mixing dry soil and fibers using a concrete mixer for 5 min until a homogeneous color of mixture was obtained, then water was added to the mixture that was continuously being mixed for 5 min. The optimum water content was determined by the proctor test [23]. Afterward, the mixture was placed into steel molds dimension (295 mm x 145 mm x 95 mm) and then, compacted with static loading pressure of 10 MPa. After demolding, the drying of the samples took place in normal laboratory conditions at 20 ± 2 °C with a relative humidity of 98% for approximately 28 days until constant weight, the main steps for the production of the CEBs are indicated in Figure 3. And the curing conditions to avoid unwanted waiting are shown in Figure 4, in which the blocks were cured at 105 °C for 24 h before testing.

Fig. 3. main steps in the production process of CEBs, including 1. the filling of the mold 2. the block after compacting stress, and 3. Produced CEBs

Fig. 4. Cured CEB samples in the oven

Table 3. The proportion of mixtures of CEB

	Composition for (Different Fiber Contents)
Soil in relation to the dry soil (%)	100
Fibers in relation to the dry soil (%)	0
	0.20
	0.40
	0.60
	0.80
Water in relation to the dry soil	13.50

2.3 EXPERIMENTAL TESTING

The physical properties of the CEB samples containing different contents of Juncus fibers, including the dry unit weight, as concluded by means of dimensional measurements and weighing after 28 days of curing, were established as shown in figure 5.

Fig. 5. Weight measurement of block

2.3.1 ULTRASONIC TESTING

The ultrasonic pulse velocity (UPV) was evaluated on samples as specified in Standard NF P 18–418 [24]. This non-destructive test is based on the propagation of ultrasonic waves in the tested material. Thus, the time transmission was measured using a UPV tester (Figure 6). The velocity of the pulse through the specimen was evaluated using Equation (1):

$$V = \frac{d}{t} \tag{1}$$

Where V (m/s) is the velocity of the ultrasonic pulse, d (m) is the path length of the sample, and t (s) is the traverse time of the pulse.

Fig. 6. Ultrasonic pulse velocity tester

2.3.2 COMPRESSIVE STRENGTH TEST

Three specimens from each produced mixture of CEB were tested for compressive strength. In this test, the compressive strength of blocks is measured. It requires applying a compressive force to a hardened block until rupture occurs. It was carried out with a maximum load capacity of 3000 KN, a Hydraulic IGM—France machine was used to record the highest load supported by the sample during the test (Fig. 7). A constant pressure rate of 0.15 MPa/s was applied to the load. Following that, every block's compressive strength was determined using Equation (2):

$$\sigma c = \frac{Fc}{S} \tag{2}$$

Where σc (MPa), Fc (N), and S (mm^2) are the compressive strength, the maximum failure force and the contact surface between the block sample and plates used in the test, respectively.

Fig. 7. Compressive strength test

2.3.3 Dry Abrasion Test

The dry abrasion resistance test was performed on the specimens. It was carried out according to the AFNOR, XP P13-901 [41] made for CEBs, by measuring the removed quantity of material from the blocks after 60 back and forth brush sweeps using a steel brush. During the test, the steel brush (Fig. 8) was used to brush the block surface (roundtrips) once every second for 1 min without exerting any additional vertical force on the brush. Brushing was performed along the entire length of the block, and at least half of the brush surface remained in permanent contact with the surface of the block during the entire test to avoid a cantilever that would put too much stress on the edges of the block. At the end of the brushing, the block was cleaned of the elements that had become detached. A coefficient of abrasion in cm^2/g assessment was based on Equation (3):

$$\mathbf{Ca} = \frac{\mathbf{S}}{\mathbf{mo-m1}} \tag{3}$$

where mo is the mass before brushing, $m1$ (g) is the mass after brushing (g), and S is the brushed surface (cm^2).

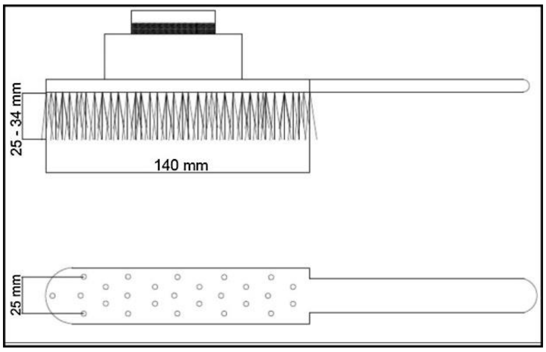

Fig. 8. Steel brush for dry abrasion test

3 Results And Discussion

3.1 Apparent Density

The density, defined as mass per unit volume (ρ = m/V), is a fundamental property of building materials that governs their structural performance, thermal behavior, and acoustic characteristics and their suitability for building applications. In this work, the apparent density of the blocks was evaluated.

The figure 9 shows the evolution of bulk density as a function of Jancus plant fiber. It can be clearly seen from the results that the bulk density decreased as the fiber incorporated into the mixture. As expected, it was noticed that value of density decreased as the content of fibers increased. Consequently, this behavior could be related to the low density of juncus fibers, which induce a decrease in the compressed earth block bulk density. Moreover, it was seen that the value of bulk density dropped from 1724 Kg/m3 (0% fibers) to 1525 Kg/m3 (0.8% fibers). It is also interesting to note that increasing the juncus fiber level from 0.2% to 0.8% caused decrease from 3.53% to 11.54% on the value of bulk density compared to earth block without fiber.It should also mentioned that these values these findings are in good agreement with those previously reported in the literature [25], [26].Where several researcher studies highlighted that the addition of vegetal fibers into earth blocks lead to reduce the bulk density.

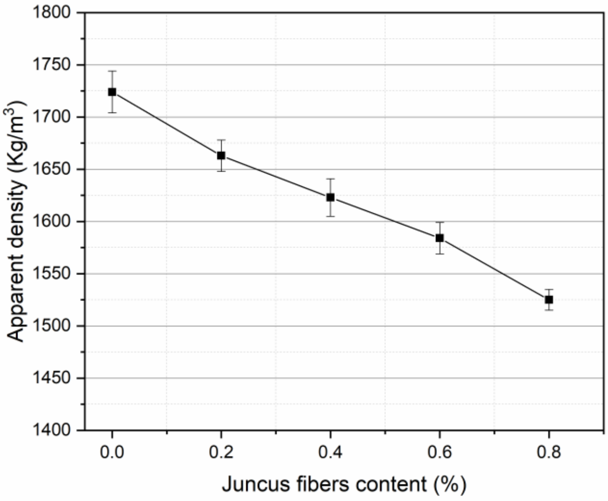

Fig. 9. Apparent density of CEB samples at different fiber replacement levels

3.2 Ultrasonic Pulse Velocity

The ultrasonic pulse velocity (UPV) test was conducted to assess the porosity of the CEB and its capacity to absorb sound. The figure 10 depicts the effect of juncus fibers on the ultrasonic pulse velocity of compressed earth blocks. As it can be clearly observed from the graph that the values of UPV were influenced by the presence of juncus plant fibers. Moreover, from the results it can be seen that the increase of fiber content caused decrease on the value of UPV of the CEB samples. the values of UPV varied from 1500 m/s for 0% fiber to 1099 m/s per 0.8% fiber. Furthermore, the block sample incorporating 0.8% of fiber presented the lowest value of UPV of all compressed earth blocks, this value diminished by approximately 26.73% compared to earth composite without fibers. In addition, this decrease might be certainly explained by the lowest UPV wave when it confronts the air-filled pores as results from the integration of plant fibers. In this regard, it should be noted that sound insulation coefficient of earth-concrete is lower than that of vegetal fibers. These finding are in good line with earlier work published in the literature [6], [21], [27], [28]. These earlier works demonstrated that construction material composites including vegetable fibers have good sound absorption characteristics.

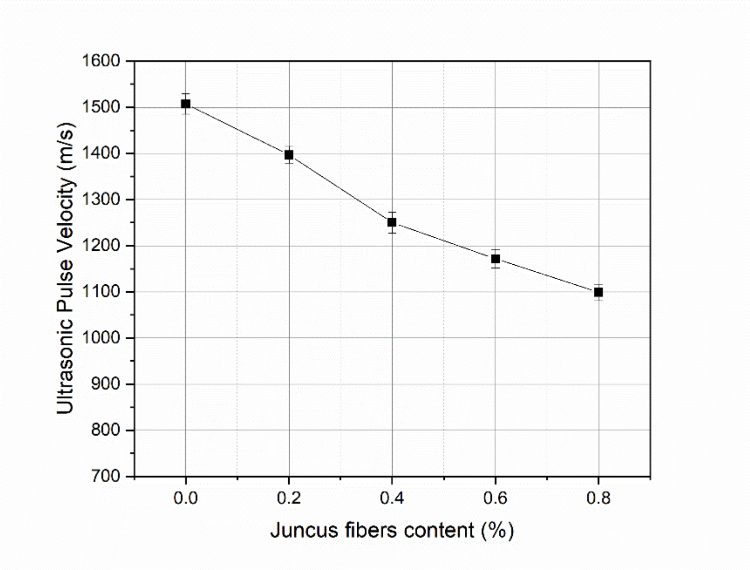

Fig. 10. Ultrasonic pulse velocity as a function of fiber content

3.3 COMPRESSIVE STRENGTH

In this study, the compressive strength of compressed earth blocks filled with Juncus fibers after 28 days of curing in a laboratory condition was studied dry state. This is because the compressive strength of earth bricks is considered to be an important indicator of masonry strength. The following sections summarize the obtained results of compressive strength tests performed on the block in dry conditions.

Figure 11 shows the variation of dry compressive strength (DCS) of earth block filled by juncus fibers. From the graph, it can be observed that dry compressive strength of block without fibers was higher than that of all the specimens. Moreover, DCS ranged from 3.55 MPa to 5.16 MPa. It was concluded that when Juncus fiber level increased from 0% to 0.8%, the compressive strength of earth blocks went down. This finding was also highlighted earlier by authors who investigated the influence of that date palm fibers on the compressive strength of compressed earth blocks [10]. In this context other studies reported that when fiber content of the simple increased the area of bonding between the matrix and the fiber become larger, which results in a decrease of the strength value of block [29], [30], [31]. Furthermore, the drop of compressive strength of blocks may be related to the incorporation of juncus plant fibers, which have low stiffness and compressive strength compared to the earth matrix. Finally, it was found that compared to the block sample without fibers increasing juncus plant fiber content from 0.2% to 0.8% engendered the the value of dry competitive strength to decrease from 13.17% to 31.20%. Despite the reduction seen in strength, the values found for DCS were satisfactory, since it is recommended that the dry strength for CEBs be greater to 2.4 MPa at 28 days according to Houben et al [32].

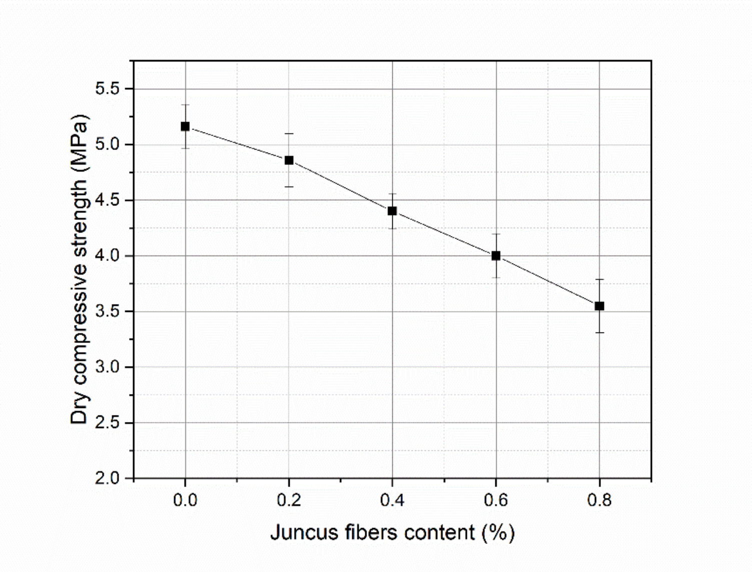

Fig. 11. Result of dry compressive strength as a function of fiber content

3.4 Erosion Resistance

Figure 12 depicts the evolution in the abrasion resistance coefficient (ARC) as a function of Juncus fiber content. The higher the ARC of the block, the greater its durability performance in terms of abrasion resistance. two samples were tested for each formulation. As can be observed when juncus fiber increased in the composite, the ARC of block samples decreased. The block with a high content of fibers (0.8%) had the lowest value of ARC, 1.32 cm2.g−1, whereas the highest value was 2.15 cm2.g−1, corresponding to the block without fibers. In comparison with the unreinforced specimen (CEB without fiber), when the fiber level passed from 0.2% to 0.8%, the ARC decreased from 8.83% to 38.60%. Consequently, the earth blocks filled with juncus plant fiber exhibited lower resistance to abrasion in comparison to unfilled block. This behavior can be due to the morphology of Juncus fibers, characterized by a smooth external surface, contributing to weakened bonding between the fibers and the matrix. It can be concluded that the higher the compressive strength, the better the durability of the block. Figure 13 displays the samples after being subjected to abrasion tests.

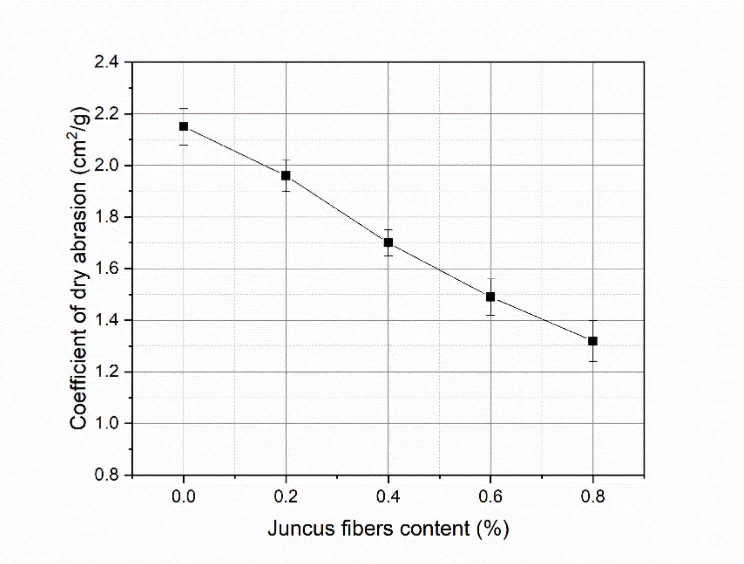

Fig. 12. Effect of fiber content on the abrasion coefficient of CEBs

Fig. 13. Blocks after abrasion test

4 Conclusions

In this study, we studied the effect of juncus plant fiber content on the physical, mechanical and durability properties of compressed earth blocks. According to the experimental tests, the following conclusions could be drawn:

The apparent density of the CEB containing 0.80% Juncus fibers was reduced by approximately 12% in comparison to the CEB composite without fibers,

The impact of Juncus fibers on the ultrasonic pulse velocity was favorable to promote sound insulation characteristics and damping vibration, owing to the reduction in its value by up to 26.70 % for blocks filled by 0.80% fiber content.

The incorporation of Juncus fibers from 0 to 0.8% results in a decrease in the dry compressive strength of CEBs.

The durability criteria were respected based on the results of the experimental resistance to abrasion tests.

These findings lead us to the conclusion that good properties can be obtained in a CEB composite, which can provide safe, comfortable, and long-lasting building materials, based on juncus fibers as a reinforcement.

Author Contributions

Reda SADOURI: Conceptualization, Investigation, Visualisation, Methodology, Testing, Writing original draft, Validation, Writing—Review and editing.

Farah CHANTIT: Conceptualization, Investigation, Visualisation, Methodology, Testing, Writing original draft, Writing—Review and editing.

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Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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