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PRACTICE-ORIENTED PAPER

Performance of sisal fiber-reinforced cement-stabilized compressed-earth blocks incorporating recycled brick waste

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Abstract

Recently, studies are oriented to introduce sustainable materials in construction. This study aims to investigate the effects of sisal fibers on the thermophysical and mechanical properties of compressed earth blocks (CEB) made of local materials by mixing red clayey soil taken from the M'sila region in Algeria and brick waste (BW). First, the maximum percentage of BW is fixed at 20% while respecting the plasticity criteria. Then, the effects of fibers and cement addition on the engineering properties of CEB are analyzed and compared according to fiber and cement contents. Sisal fibers are added with different percentages varying from 0 to 0.5%, while cement content is used with four percentages: 0, 5, 7, and 9% (by wt% of the newly modified soil). Many tests are performed including, capillary absorption rate, thermal conductivity, compressive/tensile strengths, and abrasion resistance. The results showed that the inclusion of sisal fibers improves the thermal insulation of cement-stabilized blocks by up to 21% and strength by 150%. However, it is observed that the hydrophilic character of sisal fibers increases the capillary absorption by 81%, and the abrasion coefficient increases with the increase in fiber content. Furthermore, the investigation revealed that the use of fibers alone is insufficient to ensure the stability of the blocks in moist conditions since the material fully loses its resistance, which requires the total protection of material against any type of infiltration and/or the use of cement as stabilizing agents. As a result, the research showed that sisal fibers may be used in CEB reinforcement, further an environmentally alternative solution was proposed for managing BW by their use in CEB manufacturing as this contributed to sustainability and circular economy strategies.

Keywords Compressed earth block · Thermal insulation · Sisal fibers · Recycling · Strength

Introduction

Using energy efficiency measures in construction played an important role in improving heat/cooling systems, controlling energy consumption, and reducing CO_2 emissions. The current state of research in the field of construction materials is oriented toward integrating alternative materials to reduce the adverse effects associated with the use of gray materials. Among the solutions highly recommended by scientists is using earth construction techniques [1]. It was assumed that 30% of international energy production resulted from building sectors [2] and it will rise by another 30% by 2060 [3]. Researchers [2, 4–6] indicated that low-carbon materials might be obtained by the integration of raw materials and/or the incorporation of industrial by-products and wastes. Therefore, these processes help to create ecofriendly and sustainable products, reduce pollutant emissions, improve energy recovery, and contribute to circular economy strategies [7].

Since ancient civilizations, the earth has been widely used as a construction material due to its availability, low costs, ease of construction, and being socially accepted [8]. In addition, earthen materials are characterized by very interesting thermal properties which reduced energy consumption and offered economic and environmental benefits. In comparison with concrete material, using earthen materials in construction significantly reduced operational and transportation energy.

The mechanical properties of traditional masonry blocks called adobe when they improved by compaction under high efforts created CEB. Although, CEB presented certain limitations in comparison with modern construction materials

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including water penetration and cracking strengths. To remedy this problem, many additives were used to reinforce/stabilize CEB including fibers, cement, lime, bitumen, and other waste materials. The principle of functioning of these additives is based on a chemical process for hydraulic binders, a mechanical mechanism for fibers, or the interaction between them. Many factors can affect therefore the performance of CEB such as granulometric size distribution of soil, the plasticity of soil, cement content, type, and dosage of fibers [1, 9].

For CEB material, Walker [10] recommended using soil with a plasticity index ranging from 5 to 15 to produce CEB, while Mesbah et al. [11] reported that the cement dosage used for CEB should be comprised between 4 and 10% of the dry mass of soil. However, other researchers [12, 13] indicated that using higher percentages of binder (> 10%) was not economic for CEB.

Fibers were used effectively in civil engineering to reinforce both soil and cement-based materials [14–18]. Therefore, when fibers are incorporated they contributed to improving crack resistance, strength, ductility, durability, and insulation aspect [19–21]. For CEB material, researchers [20–22] indicated that the fibers contributed to improving crack resistance, tensile strength, shrinkage, thermal behavior, and durability. Therefore, it was reported that natural fibers were more beneficial than synthetic fibers to produce CEBs [23]. So, natural fibers are available in abundance, biodegradable, and have low costs. More recently, the efficiency of using lignocellulosic fibers as reinforcements for CEB has been proved by many studies, therefore many kinds are used including, date palm fibers [24], kenaf fibers [25], banana fibers [26], hibiscus cannabinus fibers [27], and doum fibers [28]. Furthermore, few studies have been focused on the effectiveness of sisal fibers for CEB [1, 29] and therefore little information is available on the effects of such types of fibers on the engineering properties of CEB. In addition, the scientific mechanisms between sisal fibers and soil particles are not sufficiently defined. To this end, the effects of sisal fiber inclusion on the physical, mechanical and thermal properties of CEB were experimentally investigated in this paper. Besides, the study emphasizes also an environmentally attractive solution by incorporating brick waste in CEB to make a sustainable product. The brick manufacturing industry generates large quantities of BW from non-standard bricks (i.e., broken, deformed, underburn, or overburned) [30]. Hence, their use can absorb some quantities of these wastes and creates alternative aggregates. Besides, this strategy contributes directly in circular economy and sustainability.

Experimental

Materials

- Soil

A red clay collected from the Chaaba El Hamra region in M’sila, Algeria was used to produce CEB. Figure 1 shows the granulometric distribution curve for this soil carried out as per NF P 94–056 [31]. Plasticity characteristics were determined with Atterberg limits and Methylene blue tests as per NF P 94–051 and NF P 94–068, respectively. Accordingly, the results indicated that the clay used in the study is classified in the category of low-plastic clays (USCS classification). The physical and chemical properties of this clay are shown in Table 1, whereas the X-ray diffractogram is presented in Fig. 2. The soil composed is mainly of aluminosilicates (34.68% of silica 9.16% of alumina) and a relatively high content of calcite (22.52%). The compaction behavior of this clay is characterized by a maximum dry density of 20.05 kN/m^3 and optimum moisture content of 12.5%.

- Cement

Portland cement CEM II/B class 42.5 according to EN 197–1 [32] from Ain Touta factory with a density of 3150 kg/m^3 was used as stabilizer. The chemical composition of this cement is shown in Table 2. As indicated in many studies [11–13], the most effective cement dosage for CEB should be ranged between 5 and 10%. So, three cement contents are chosen in this interval (5, 7, and 9%).

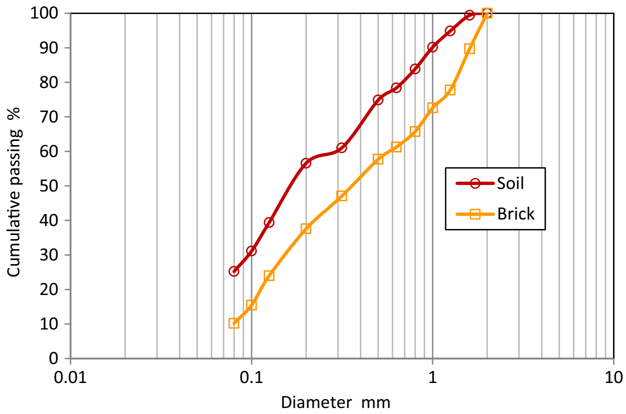

Fig. 1 Granulometric distribution curves for clay and brick waste

Table 1 Physical and chemical properties of the clay used

	Property	Value
Physical properties	Specific density (kg/m^3)	2500
	Methylene blue value (g/cm^3)	1.62
	Liquid limit, %	26
	Plastic limit, %	18
	Plasticity index, %	8
Compaction characteristics	Optimum water content, %	12.5
	Maximum dry density, kg/m^3	20.05
Chemical composition, %	SiO_2	34.68
	Al_2O_3	9.16
	Fe_2O_3	3.44
	CaO	22.52
	MgO	4.66
	SO_3	0.94
	Cl	0.63
	K_2O	1.1
	Na_2O	0.14
	PF	22.98

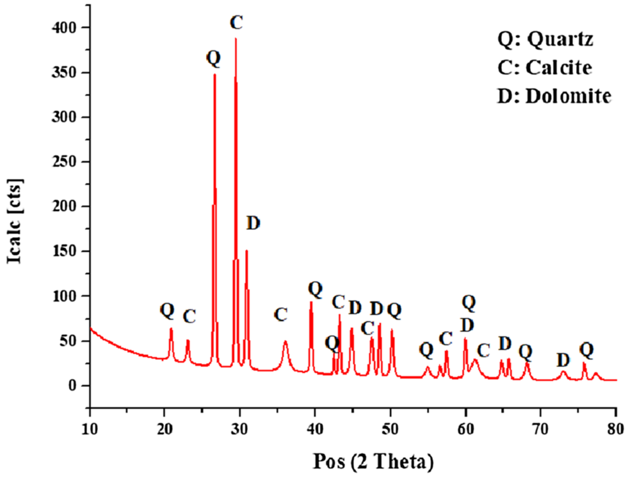

Fig. 2 X-ray diffractogram of clay

- Fibers

Commercialized sisal fibers with 40 mm in length, 0.2–0.4 mm in diameter, and 500 MPa of tensile strength were used to reinforce CEB (Fig. 3). The fiber length was kept constant for all the tests based on literature [25, 33–35]. These fibers are locally available and commonly used in civil engineering applications such as soil stabilization and plaster-panel reinforcement. Further, they were characterized by high initial tensile strength similar to polyester fibers, which can be considered good reinforcements [36, 37].

Fourier Transform Infrared spectrometer (FTIR) analysis spectra of sisal fibers are shown in Fig. 4 and some indications on bands obtained are summarized in Table 3. The details of peaks and the type of chemical stretching are defined in comparison with the investigation of [38]. Five concentrations were used to reinforce the blocks varying from 0.1, 0.2, 0.3, 0.4, and 0.5% of the global dry mass of all ingredients.

- Brick waste

Brick waste with a specific density of 2358 kg/m^3 collected from construction sites was used in this study. Its granulometric size distribution and chemical composition are shown in Fig. 1 and Table 4, respectively.

Mix design and procedures

The procedure followed in the study to analyze the effects of sisal fibers and cement on the engineering properties of blocks is shown in the flowchart of Fig. 5. According to the specifications of CRATerre (International Centre on Earthen Architecture) [39], the soil that will be used to produce CEB blocks should be satisfied the criteria of plasticity. Therefore, the soil is located within the limits as mentioned in Fig. 6. Among the objectives of this study consisted to incorporate BW in CEB for producing eco-friendly material. In this sense, the maximum possible percentage of BW while respecting the requirements cited above was fixed at 20% as indicated in Fig. 6.

For each dosage of cement, the optimum moisture content was determined using the Proctor test. But, it should be noted that fresh blocks were consolidated with static effort using a hydraulic press because the dynamic impact commonly used in the Proctor test is inappropriate for CEB material as reported in many studies [40, 41]. To study the effects of both fibers and cement stabilization on the engineering properties of CEB, a total of 24 mixes were formulated as shown in Table 5. For all tests, the mean arithmetic of three values was considered.

Blocks of 70 × 70 × 280 mm^3 were used for mechanical characterization as per XP 13–901[42]. Compressive strength was determined at dry and saturated states to simulate its behavior, respectively, at normal and extreme weather conditions. The test was conducted based on the standard XP 13-901 [42], as shown in Fig. 7. Splitting tensile strength was determined from blocks loaded with

Table 2 Chemical composition of cement

Element	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Cl	K_2O	Na_2O	PF
Cement, %	21.45	4.31	4.56	61.43	1.24	2.28	0.018	0.61	0.39	2.19

Fig. 3 Aspect of sisal fibers used

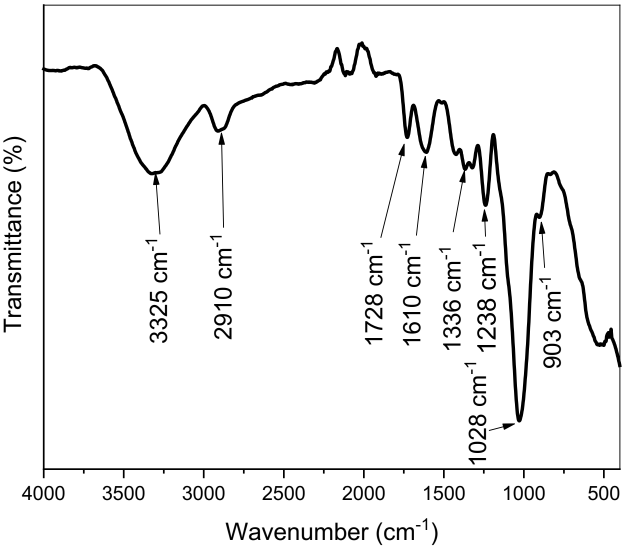

Fig. 4 FTIR analysis of sisal fibers

Table 3 Definition of FTIR peak positions

Wave number (cm^{-1})	Origin
3325	N–H stretching (amide)
2910	C–H stretching
1728	C=O stretching of hemicellulose
1610	OH absorbed water
1336, 1238	C–O stretching
1028, 903	C–OH stretching of lignin

linear concentric compressive effort in a similar manner as the Brazilian test as described in RILEM TC 164-EBM [43]. Capillary absorption test was conducted on partially immersed specimens (see Fig. 8) as described in XP 13-901 [42]. Abrasion resistance was quantified according to the recommendations of AFNOR XP P 13 901 [42] and NTC 5324 [44]. The test consisted to express, for a specific surface, the mass loss when the block was solicited by abrasive effort using a steel brush as mentioned in Fig. 9. The thermal conductivity was measured using a CT-meter device as per ISO 8894-1:1987 as shown in Fig. 10.

To produce relatively homogenous material and reduced the variability of samples, the soil was previously mixed with BW in the dry state and then they mixed for 60 s. After fibers were added and the ingredients were mixed again for 60 s. The required water was added and the ingredients were mixed again for 180 s. The mix was placed in a rigid mold then the soil was immediately compacted in a hydraulic press since this method was more appropriate for CEB blocks as reported in many investigations [24, 41, 45]. All specimens were produced with the same compaction stress of 6 MPa.

After fresh blocks were removed carefully from molds and there were stored in plastic bags in laboratory conditions until the date of the test. Unstabilized soil specimens are stored for 14 days, while cement-stabilized blocks are cured for 28 days. Before testing CEB blocks are dried in an oven until mass stabilization as per the standard (XP 13-901) [42].

Table 4 Chemical composition of brick waste

Element	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Cl	K_2O	Na_2O	PF
BW, %	32.45	9.84	4.31	21.19	2.76	5.89	0.371	0.86	0.97	20.94

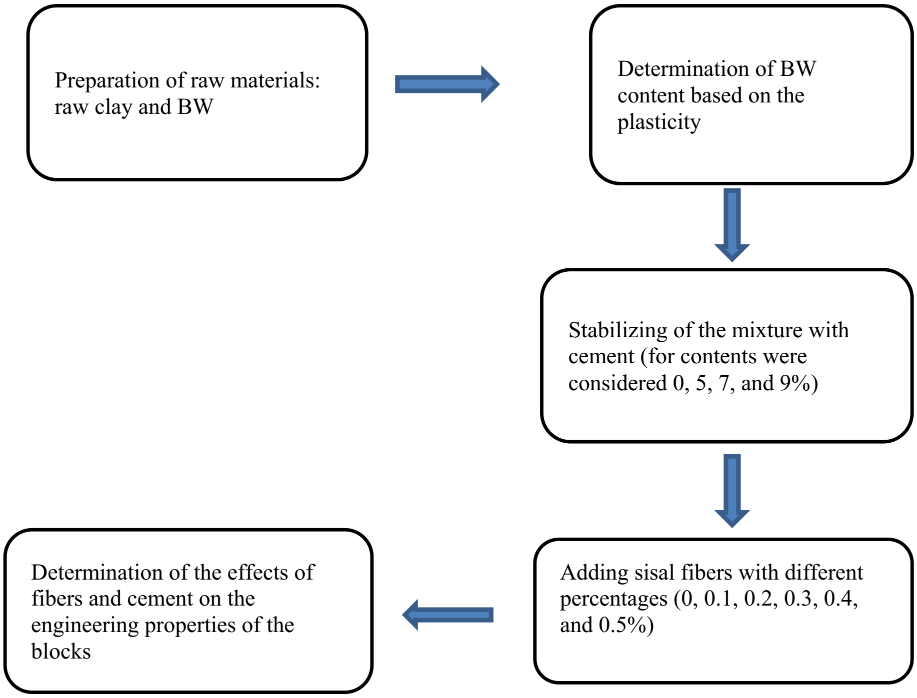

Fig. 5 Flowchart of the procedure used in the study

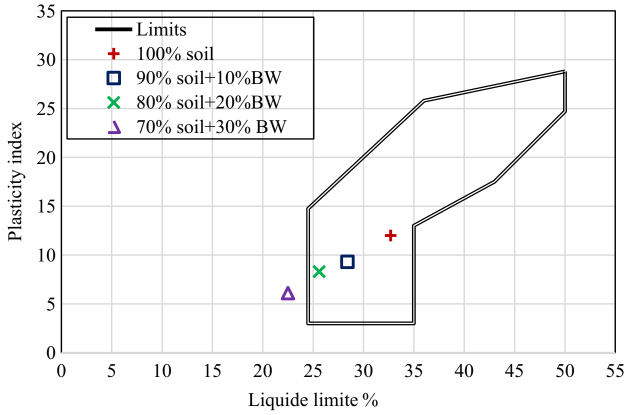

Fig. 6 Position of different mixes in the plasticity charts as per XP P13 901 [42]

Results and discussion

Physical properties

Thermal conductivity

Figure 11 showed the effect of fibers on the thermal conductivity of fiber-reinforced and cement-stabilized fiber-reinforced samples. For fiber-reinforced CEB, it was observed that the thermal conductivity decreased as the fiber content increased in the mix. For example, with 0.5% of fiber addition, the thermal conductivity decreased by

Table 5 CEB mix proportions

Mix	Soil (%)	BW (%)	Cement (%)	Fibers (%)
C0F0	80	20	0	0
C0/F0.1	79.92	19.98		0.1
C0/F0.2	79.84	19.96	0	0.2
C0/F0.3	79.76	19.94		0.3
C0/F0.4	79.68	19.92		0.4
C0/F0.5	79.60	19.90		0.5
C5F0	76	19	5	0
C5/F0.1	75.92	18.98		0.1
C5/F0.2	75.84	18.96		0.2
C5/F0.3	75.76	18.94		0.3
C5/F0.4	75.68	18.92		0.4
C5/F0.5	75.60	18.90		0.5
C7F0	74.40	18.60	7	0
C7/F0.1	74.32	18.58		0.1
C7/F0.2	74.24	18.56		0.2
C7/F0.3	74.16	18.54		0.3
C7/F0.4	74.08	18.52		0.4
C7/F0.5	74.00	18.50		0.5
C9F0	72.80	18.20	9	0
C9/F0.1	72.72	18.18		0.1
C9/F0.2	72.64	18.16		0.2
C9/F0.3	72.56	18.14		0.3
C9/F0.4	72.48	18.12		0.4
C9/F0.5	72.40	18.10		0.5

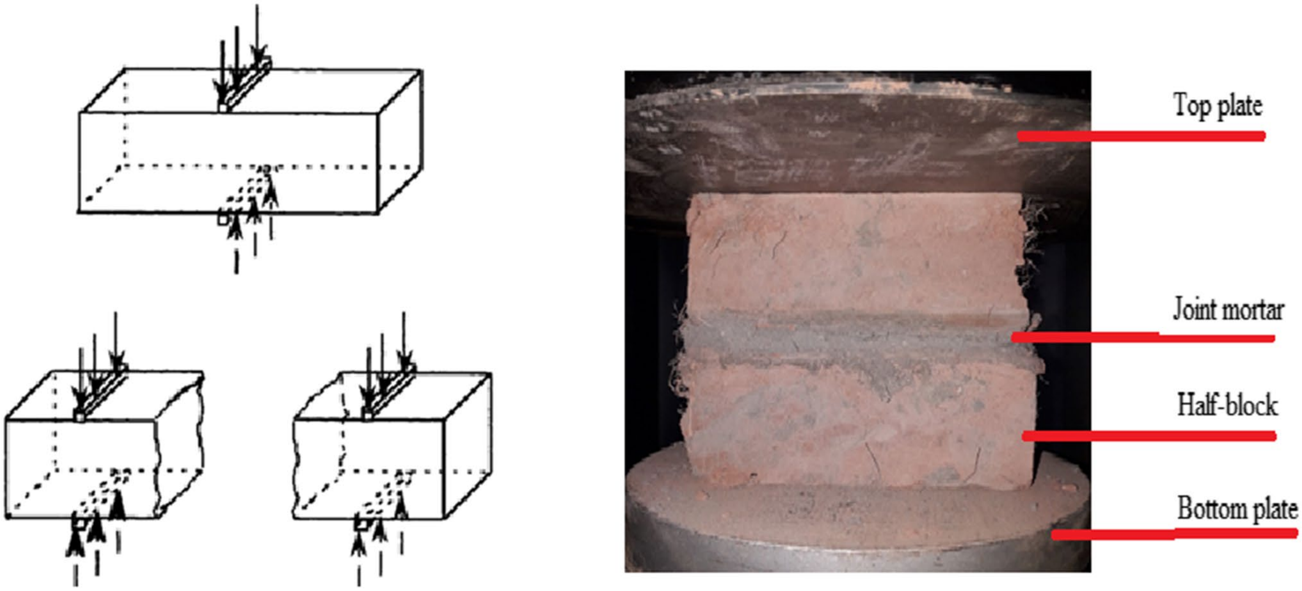

Fig. 7 CEB specimen during compression test according to the method of XP P13 901

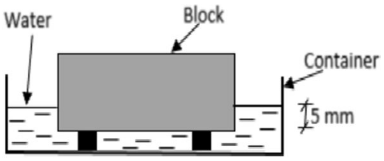

Fig. 8 Schematic setup for water absorption by capillary

15% in comparison with unreinforced CEB. The decrease in thermal conductivity might be explained by the fact that fiber addition generated more voids which increased the porosity and consequently created an open Skelton. Similar results were obtained in previous investigations [35, 46–48].

Fig. 9 Abrasion test: Steel brush used (left), specimen aspect after the test (right)

Fig. 10 Measurement of thermal conductivity of CEB using the commercial CT-meter device

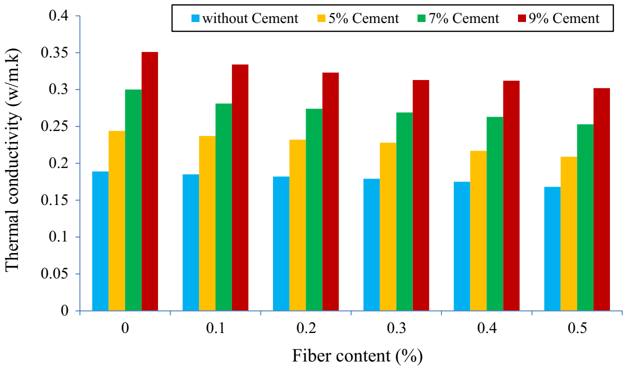

Fig. 11 Effect of fibers and cement addition on thermal conductivity

For cement-stabilized fiber-reinforced CEB, it was observed that for a given cement content, the thermal conductivity decreased as increasing of fiber content. Therefore, for 0.5% of fiber addition, the thermal conductivity decreased by 17, 19, and 21% for cement content 5, 7, and 9%, respectively. So the same argument utilized to justify the decrease in thermal conductivity of fiber-reinforced CEB can be used for the case of cement-stabilized fiber-reinforced CEB. On the other hand, it can be seen also that for a given fiber content, the thermal behavior increased with the increase in cement content. Similar observations were stated by Zakham et al. [49]. The thermal conductivity changed from 0.189 to 0.24, 0.3, 0.351 (W/m k) when the control block stabilized, respectively by 5, 7, and 9% of cement. This increase in thermal conductivity resulted mainly from the hydration process between cement and soil minerals which created stronger bonds, hence reducing porous the network and increasing the rigidity in CEB material [50].

Capillary absorption test

Durability tests were conducted by studying the effect of capillary water absorption to simulate the case of humidification of CEB-based walls from the bottom by capillary. In addition, researchers indicated that coefficient absorption (C_b) gave a sufficient idea on the performance of CEB [51]. From the bar chart shown in Fig. 12, it can be seen that the absorption coefficient is significantly affected by incorporating fibers and cement.

First, the blocks made only with soil and BW (uncemented, unreinforced) have very low water resistance, once the blocks moistened they started to dissolve as seen in Fig. 13. However, in the presence of fibers, the blocks remained partially intact. Thus, stated that the sisal fibers contributed to decreasing the sensitivity of CEB to water. Therefore, it could be noted that using fibers only to reinforce CEB blocks is insufficient to ensure the long-term stability of CEB in moist conditions, which required a chemical agent to create some adhesion between soil particles.

Second, for cement-stabilized fiber-reinforced CEB, it was observed that for a given cement content the absorption coefficient was increased with the increase in fiber content. In comparison with unreinforced blocks, the absorption coefficient of 0.5% fiber-reinforced blocks increased by 81, 71, and 7% when they stabilized by 5, 7, and 9%, respectively. These findings agree with that reported in previous studies [52, 53]. The authors stated that the addition of fibers led to increasing water absorption of laterite bricks. Ghavami et al.

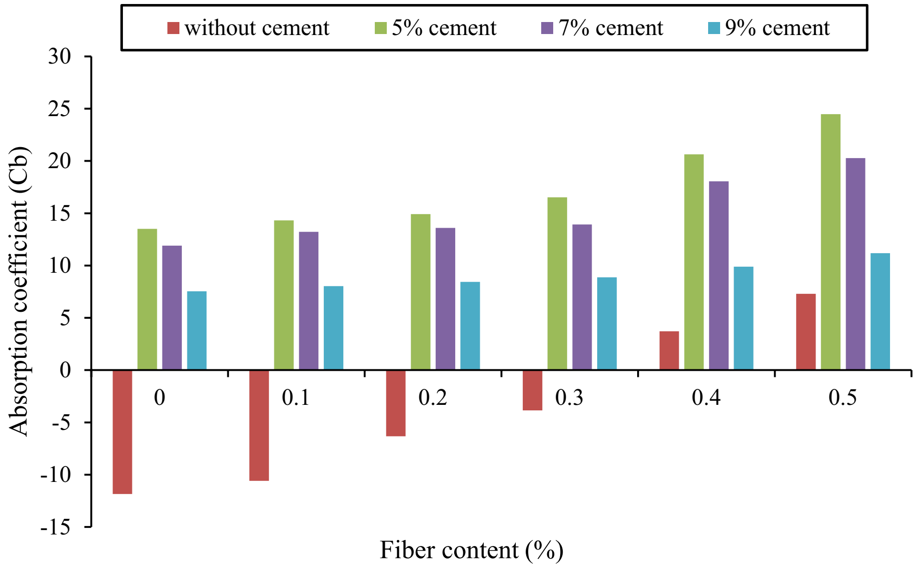

Fig. 12 Effect of fibers and cement additions on the capillary absorption

Fig. 13 Aspect of blocks after their immersion in water

1999 [33] indicated that vegetal fibers created more voids and generated pathways through soil particles.

On the other side, it is observed that the absorption decreased with increasing cement content as shown in Fig. 12. Cement addition played a positive role to reduce the absorption rate by creating stronger bonds between soil particles. Thus, reducing the porosity and flocculated soil components [54]. Even though the increase in absorption coefficient, it should be noted that this material is considered as low capillary as per NF XP 13-901 [42].

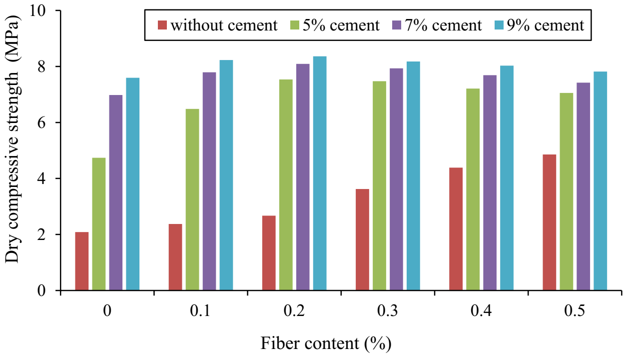

Fig. 14 Variation of dry compressive strength of CEB

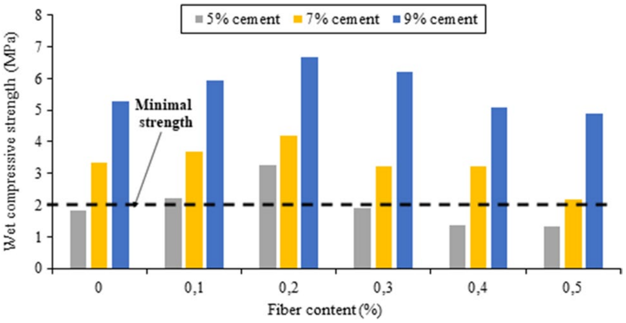

Fig. 15 Variation of wet compressive strength of CEB

Strength tests

Compressive strength

The 28-day dry compressive strength of different blocks produced is shown in Fig. 14. From the results, it can be seen that both cement and fiber addition improved the strength, however fiber-reinforced and cement-stabilized fiber-reinforced possessed different behaviors.

First, the compressive strength of fiber-reinforced CEB regularly increased with the increase in fiber content. It changed from 2 to 5 MPa when fibers were incorporated at a rate of 0.5%, which indicated an improvement of 150% in comparison with the unreinforced sample. This behavior is mainly attributed to the presence of fibers. They supported therefore some part of the applied load which increased friction between soil particles. Indeed, the interaction between soil and fibers increased the contact forces between soil particles. It was reported that fibers when associated with soils, created an additional cohesion in the composite and improved thereby the performance of earth-based materials [17]. Furthermore, it was important to mention that CEB should have a minimum strength of 2 MPa as recommended in [55]. This condition was already satisfied for fiber-reinforced CEB. Further strength obtained in this work, was higher than that obtained in other studies [35]. Thus, might be justified by the type of soil and strength of the fibers used.

Second, strength developed by cement-stabilized fiber-reinforced blocks characterized by peak value then further a decrease in strength observed after the optimal values. Therefore, the effect of fibers was more remarkable at relatively low cement contents and the sensibility of strength was decreased as cement content was increased. For all cement concentrations, it was observed that the most effective fiber content was 0.2% and strengths developed after the optimal values were relatively comparable. Further strength was near to 8 MPa which signified that was possible to increase strength at low cement content which was environmentally advantageous to reduce the use of cement. In the case of cement stabilization, the strength resulted mainly from the reaction between cement and water which created sufficiently rigid hydrates filling voids and binding particles together. Further, pozzolanic reactions take place with clay minerals and calcium hydroxide ($Ca(OH)_2$) formed by cement hydration [56, 57].

In literature researchers justified the decrease in strength of cement-stabilized fiber-reinforced CEB after the optimal fiber content by the fact that the interaction between fibers and matrix mobilized, further fibers created more voids which reduced the strength [52, 58].

The wet compressive strength was used to analyze the behavior of CEB in extremely worst conditions. Further, some researchers considered this parameter as a durability indicator [59]. Therefore, the test consisted to determine the compressive strength after 2h immersion of CEB in water. The results obtained are shown in Fig. 15. As for the dry state, saturated compressive strength results showed two distinct behaviors (i) the fiber-reinforced blocks were fully or partially dissolved after their immersion in water which led to neglect of the strength (ii) cement-stabilized fiber-reinforced blocks remained intact and more consolidated.

Accordingly, based on these findings and considering the dry strength results presented above, fiber-reinforced blocks may be used in earth construction with the condition of its coating with impermeable material to prevent any form of water penetration.

From Fig. 15, it can be seen also that the wet strength was increased with the increase in cement content. As discussed above, the reactions between clay and cement were responsible of this improvement. These findings were in agreement with that obtained by Venkatarama Reddy et al. [60]. Moreover, the results indicated that the strength decreased as the fiber content increased. This decrease may be the result of relatively poor adhesion between fibers and matrix [24]. Although, despite this decrease in strength, the values obtained with 7 and 9% of cement addition satisfied the minimal strength of 2 MPa. However, for 5% of cement addition, the maximum percentage of fibers should be limited to 0.3%.

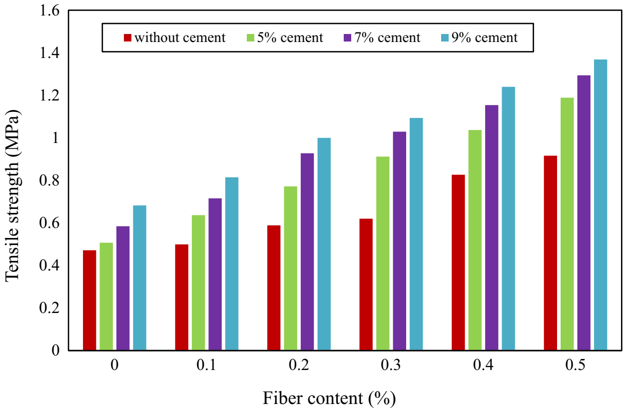

Fig. 16 Variation of dry tensile strength of CEB with fibers content and cement content

But it might be possible to use relatively high percentages with the condition of coating the CEB with impermeable material.

Tensile strength

Figure 16 shows the effect of fiber addition on tensile strength. It clearly can be seen that the tensile strength regularly increased for both cement-stabilized and cement-stabilized fiber-reinforced CEB as the fiber content increased. The increase in tensile strength as a function of the cement content is attributed to the hydration process as explained above. The effect of fibers was more remarkable in tensile than in compressive strength. These results might be explained the relatively anisotropic behavior of CEB. As the intensive compaction effort of CEB created a horizontal layer perpendicular to the compaction direction. This argument was used by other researchers when studying pavement material made with highly compaction effort in a privileged direction [61].

These obtained results were in agreement with that obtained by Millogo et al. [35]. They reported that the fibers subjected to tensile stresses improved the adhesion between the fibers and the matrix. In another study [62], it was reported that the incorporation of 1% hay fibers improved the tensile strength of fiber-reinforced clays.

Furthermore, it was observed during the test that two pieces of specimen in failure were connected for fiber-reinforced CEB; however, for unreinforced CEB the two parts of the specimen were entirely separated (Fig. 17). Therefore, the incorporation of fibers improved the absorption energy capacity and consequently increased the ductility aspect of the material in comparison with unreinforced CEB. These statements were in agreement with those obtained in other works [63, 64]. Conversely, other researchers reported that the addition of natural aggregates or fibers decreased the tensile strength [24, 65–68]. They attributed this decrease to the fiber distribution and heterogeneity of CEB [24] and the insufficient quantity of fiber addition [66].

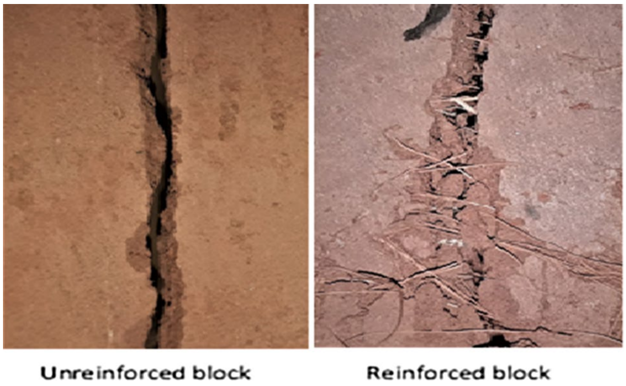

Fig. 17 Failure of soil blocks under tensile force

Abrasion resistance test

The abrasion coefficient is an important property of CEB material which can indicate the resistance under an abrasive effort. This technique consisted to quantify the loss of mass under contact friction force. Abrasion test results for fiber-reinforced cement-stabilized and cement-stabilized CEB are shown in Fig.18. The results indicated that the addition of fiber to CEB increased the abrasion coefficient. In comparison with unreinforced CEB, the abrasion coefficient increased by 20, 43, 184, 239, and 232% for samples containing 0.1, 0.2, 0.3, 0.4, and 0.5%, respectively. The improvement of abrasion resistance was due to the inclusion of fibers which created a supplementary cohesion between soil particles [17]. For cement-stabilized fiber-reinforced blocks, the abrasion coefficient was improved for blocks reinforced with 0.1% of fibers and stabilized with 5 and 7% of cement. However, for 9% cement addition the

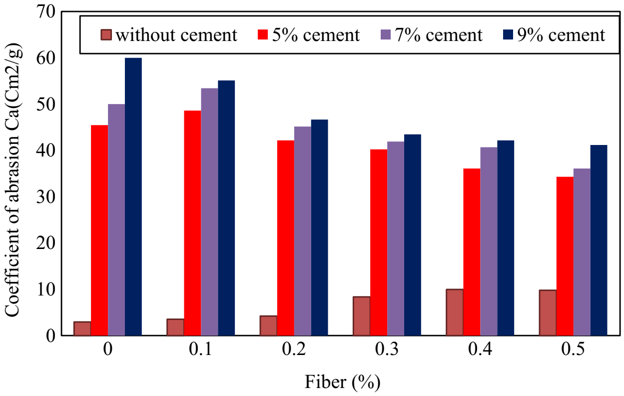

Fig. 18 Abrasion coefficients of the CEB

abrasion coefficient regularly decreased as the fiber content increased. Therefore, for the given fiber content, the abrasion coefficient was increased with the increase in fiber content. Similar results are obtained in many investigations [35, 66, 69–71]. It should be noted that the abrasion coefficient for fiber-reinforced CEB was significantly lower than that of cement-stabilized blocks as the good bond resulting from hydration increase the abrasion resistance. Furthermore, All the values of abrasion coefficient were higher than the minimum value recommended by NF XP 13-901 which is equal to 2cm^2/g.

Summary and conclusion

In this study, an eco-construction CEB was produced by using a red clayey soil collected from M'sila region in Algeria and BW. These blocks were stabilized with a combined effect between sisal fibers and cement. The results showed that the thermal conductivity regularly decreased with increasing fiber content. As an example with 0.5% of fiber addition, the thermal conductivity coefficient decreased by 15 and 21% for uncemented and cemented, respectively. Thus, reducing energy used in heating/cooling inside residents. Fiber-reinforced CEB blocks are characterized by low resistance to water even though their sensitivity decreased as the fiber content increased which required external protection to prevent water penetration. However, it is stated that cement-stabilized fiber-reinforced blocks resisted more in moist conditions which contributed to improving the durability of the blocks. In comparison with unreinforced blocks, the absorption coefficient of 0.5% fiber-reinforced blocks increased by 81, 71, and 7% for blocks containing 5, 7, and 9%, respectively. Therefore, the blocks stabilized with a combined effect between fibers and cement satisfy the requirements of NF XP 13–901 standards.

The 28d dry compressive strength of sisal fibers-reinforced CEB regularly increased as the fiber content increased in the mix. For 0.5% of fiber addition, the strength increased by 150%. However, in the case of cement-stabilized fiber-reinforced CEB, curves characterized by peak strength and then a further decrease in strength was observed after the optimal values (0.2% of fiber addition). The decrease in strength is caused by the presence of fibers which increased the porosity in the blocks compared to unreinforced blocks. Furthermore, in extremely worst conditions (saturate sate), fiber-reinforced blocks were fully or partially dissolved after their water immersion, while blocks resisted much more when they stabilized with the combined effect of cement and fibers. Further, CEB stabilized with 7 and 9% of cement addition satisfied the minimal strength (2 MPa) regardless of the fiber content; however, it should be important to limit the use of sisal fibers to 0.3% for 5% of cement addition to obtain the best performance. In terms of tensile strength, it regularly increased as the cement and fiber contents increased in the mix.

Abrasion test results indicated the coefficient of abrasion regularly decreased with increasing fiber content for cemented blocks, however for uncemented blocks increased. But, it should be noted that the values of the abrasion coefficient for both fiber-reinforced and cement-stabilized fiber-reinforced CEB satisfy the minimum value of NF XP 13–901.

Therefore, based on the obtained results the stabilization of CEB with a combined effect between sisal fibers and cement contributed to improving the insulation aspect CEB-based walls, however, it is always possible to use sisal fibers as reinforcements for CEB but it is necessary to protect the material from water penetration. Finally, this research suggested a novel environmental method by incorporating BW in CEB manufacturing.

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Declarations

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