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Physical and mechanical behavior of cement-stabilized compressed earth blocks reinforced by sisal fibers

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ABSTRACT

Nowadays, researchers are oriented to the usage of earth materials in construction as they possessed a lower thermal conductivity and thereby preserved the environment by reducing greenhouse emissions in buildings. One of these materials is the compressed earth block (CEB). Even though its attractive thermal and environmentally advantageous, CEB material present certain limitations related to its poorly strength in moist conditions, which limits its use at a high rate. The purpose of this article is to study the feasibility to improve the engineering properties of CEB produced from a red clay taken from M'sila region (Algeria) by the addition of sisal fibers, further cement is used to stabilize the composite. The fibers were added in different percentages 0; 0.1; 0.2; 0.3; 0.4 and 0.5 by total dry mass of the block. The obtained results show that the combined effect of fibers and cement improved the mechanical and physical properties of CEB material.

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1. Introduction

Build with modern construction materials consumes natural resources and causes environmental damage. Currently, 6% of the total anthropogenic global dioxide emissions are caused by the production of the Portland Cement. Because one kg of cement allows to give about 0.81 kg of CO_2 this is what leads us to the threats posed by global warming [2,10]. In addition, the cost of modern construction materials keeps increasing due to the scarcity of natural resources also the energy required for the production, high-cost transportation from the factories to the construction site. Reducing the emissions of CO_2 gases from various sources has been considered as the most major challenge for humanity to mitigate climate change. Achieving environmental and cost goals have led to a return to local materials. Researchers [1,2] reported that using these eco-friendly materials in the construction sectors help to preserve natural resources, reduces pollutant emissions, and also enhance energy recovery Earth is not new to mankind is widely used as a construction material since the ancient civilizations about 30 percent of the world's population still live in earth presently house[3] due to its availability, ease of construction, recycling, low costs and socially accepted [4]. For example, it was estimated that the construction of one square meter of earth-based masonry blocks consumes 15 times less power than conventional construction blocks [5]. Various types of earth buildings techniques that exist in different parts of the world for example adobe, mud, earth-straw, compressed earth blocks [6]. The CEB is a recent technique were improved by compaction under high efforts to obtain blocks with sufficient mechanical performances by removes the of the voids entrapped inside and increasing the density[7], but even though the use of high compaction, CEB present certain deficiencies in comparison with modern construction materials, including water penetration and cracking strengths. To overcome that, many researchers incorporate other additives including fibers, cement, lime, bitumen, and other waste materials to improve the durability and strength of soil-based materials [6-9]. The principle of functioning of these additives was based on the chemical process for hydraulic binders, a mechanical mechanism for fibers, or the interaction between them [9]. Bahar et al. [10] found that cement content enhances the compressive strength of CEB. 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, whilst other researchers [11,12] have indicated that using

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higher percentages of binder (>10%) was not economic for producing CEB. Recent researches have been used soil with natural fibers as reinforcement of earth blocks [13–15]. They reported that incorporation of fibers improve the compressive strength and increase the absorption, however other researchers [9] reported that the inclusion of fibers have a negative effect on the strength. Natural local fibers are the most economical fibers because are locally available in abundance, low energy consumption which leads us to reduction of environmental impacts [16,17].

Millogo et al. [18] showed that the incorporation of Kenaf fibers improved mainly the ductility in tension of the earth blocks and beneficial as far as the bending strength because of their strong adherence to the clay matrix and high mechanical strength of fibers. Laborel-Preneron et al. [19] have proved that a decrease of density is observed with the increase in aggregate or fiber content, also addition of aggregates or fibers increased in water absorption due to their hydrophilic nature. Recent researches have shown that the tensile and the flexural strength improved when natural fibers were used and leads to reduce the size of shrinkage cracks [20,21]. Several studies have been focused on the use of Sisal fibers as reinforcements material. Prabakar et al. [22] have found that using of Sisal fibers can be considered as a good earth reinforcement. Ojo et al. [23] have used sisal fibers to increase flexural strength and reduce water absorption in earthen building materials. Finally Wei et al. [24] Improving degradation resistance of sisal fibers in reinforced concrete. This research aims to characterize the physical and mechanical properties of sisal fiber-reinforced CEB. The novelty of this approach emphases also in recycling and valorizing brick waste an environmental attractive solution

2. Materials and experimental techniques

2.1. Materials

The local material used is a clayey soil. It was collected, crushed and sieved in order to have particles less than 2 mm in size. It is from Chaaba El Hamra region, M'sila, Algeria, available and abundant with huge quantities in this region. Fig. 1 show the granulometric distribution curve for this soil carried out as per NF P 94–056[25]. The physical and chemical properties of the soil used are represented in Tables 1 and 2. The elemental chemical analysis performed by X-ray fluorescence on this soil was performed in Fig. 2. The plasticity characteristics were quantified with Atterberg limits and Methylene blue value as per to NF P 94-051[26] and NF P 94-068 [27] respectively, and the results indicate that this soil is characterized by a low plasticity. The compaction behavior of this soil is characterized by maximum dry density of 20.05 kN/m^3 and optimum moisture content of 12.5%. Brick waste with specific density of 2358 kg/m^3 collected from construction sites is used in this study. Its granulometric size distribution is shown in Fig. 1. The chemical properties of brick waste are shown in Table 2. Portland cement CEM II/B class 42.5 according to EN 197-1 [28] from Ain-Touta factory with density of 3150 kg/m^3 is used as stabilizer to improve strength of CEB. Its chemical composition is shown in Table 2. Sisal fibers with 30–50 mm of length of diameter and tensile strength of 500 MPa are used as reinforcements for CEB blocks (Fig. 3). These fibers are available and commonly used in many civil engineering applications such as soil stabilization and plaster-panel reinforcement. FTIR analysis spectra of sisal fibers is shown in Fig. 4 and some indications on bands obtained are summarized in Table3. The details of peaks and the type of chemical stretching are defined in comparison with the investigation of [29].

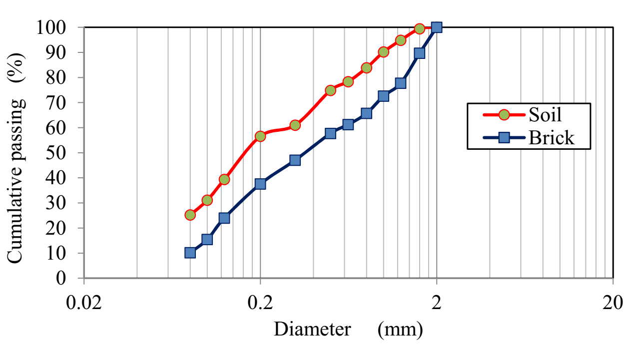

Fig. 1. Granulometric distribution curves for clay and brick waste.

Table 1
Physical properties of the clay used.

	Property	Value
Physical properties	specific density (kg/m^3)	2500
	Methylene blue value	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

2.2. Experimental techniques

This study is to incorporate brick waste in CEB for producing ecofriendly material. According to the specifications of CRATerre (Centre International de la Construction en Terre) [30], the soil will be used to produce CEB blocks should be satisfied some criteria related to its plasticity. In this sense, the maximum possible percentage of Brick waste is fixed at 20% while respecting the limits mentioned in Fig. 5. The fibers were added in different percentages 0; 0.1; 0.2; 0.3; 0.4 and 0.5 by total dry mass of the block. In addition to the fibers cement was fixed at 7% content to stabilize the composite. In order to produce relatively homogenous material and reduce the variability of samples, we must be ensured that the mixture is really dry. First, we mixing the dry mixture (Soil + waste Brick + Cement) until a homogeneous mixture was achieved. Next the fiber was spread on top and mixing again for 180 s. After that water is added and the ingredients are mixed again for 180 s.Finally, the mix is placed into rigid mold and immediately compacted in hydraulic press, because this method is more appropriate for CEB blocks as reported in many investigation [14,28,29,31,32]. All specimens were exposed to a compaction pressure of 6 MPA. The blocks are removed carefully from molds and there are stored in plastic bags in laboratory conditions for 28d. Before testing CEB blocks are dried in oven until mass stabilization as per the standard XP 13-901[33].

Prismatic specimens of 70 × 70 × 280 mm^3 are used for physical and mechanical. The density (ρ) was calculated from the ratio between the sample weight and its volume according to NF P18-559 AFNOR French standard. Capillary absorption test: This test is prepared specimens according to the XP 13-901. The block is partially immersed to a depth a 5 mm for 10 min and observe the changing in the mass during this test. Compressive strength is determined at dry this test consists to submit a sample subjected of two half-blocks superposed and bonded by a cement mortar to a simple compression until failure according to the XP 13-901. Dry tensile strength test is derived from the splitting tensile test (Brazilian test). According to RILEM TC 164-EBM testing procedure [34].

Table 2
Chemical composition of materials used.

Element	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Cl	K_2O	Na_2O	PF
Soil	34.68	9.16	3.44	22.52	4.66	0.94	0.63	1.1	0.14	22.98
Brick waste, %	32.45	9.84	4.31	21.19	2.76	5.89	0.371	0.86	0.97	20.94
Cement, %	21.45	4.31	4.56	61.43	1.24	2.28	0.018	0.61	0.39	2.19

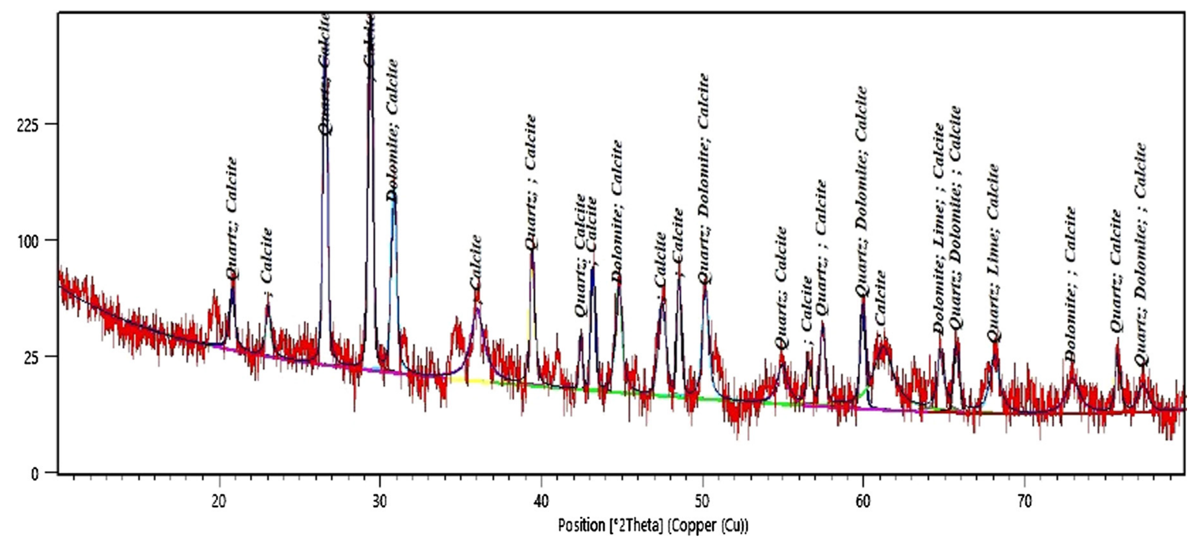

Fig. 2. X-ray diffractogram of clay.

Fig. 3. Aspect of sisal fibers used.

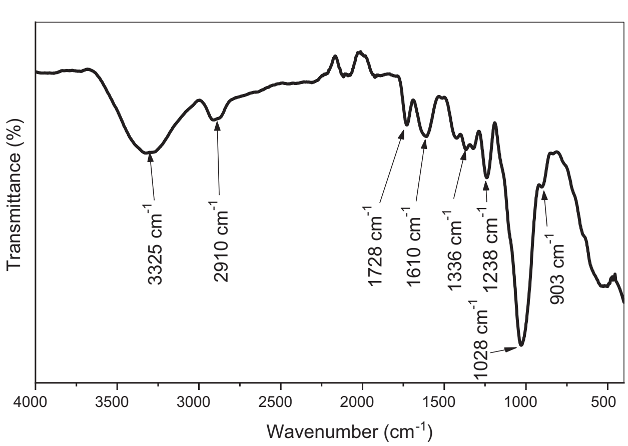

Fig. 4. FTIR analysis of sisal fibers.

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

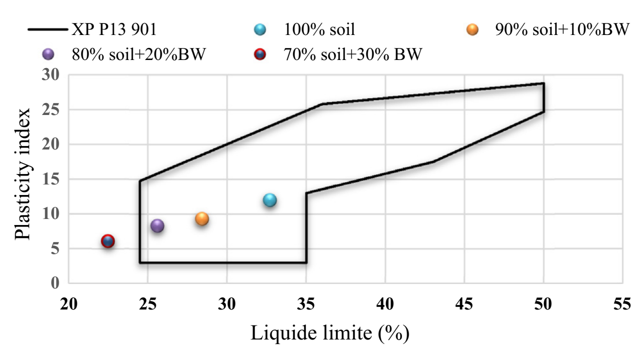

Fig. 5. Position of different mixes in the plasticity charts as per (XP P13 901) [29].

3. Results and discussion

3.1. Density

The density of samples was determined after 28 days from the date of the making. The variation of density according to the percentage of fibers is shown in Fig. 6. It can be noted that the density of mix decreases when the fibers content is increased due the low unit weight of fiber in comparison with the compressed mix,

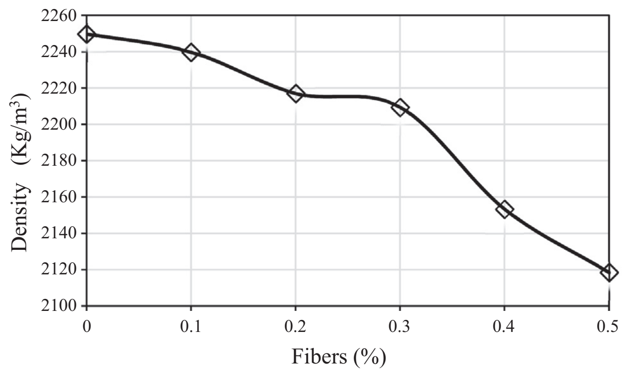

Fig. 6. Effect of fibers sisal on density.

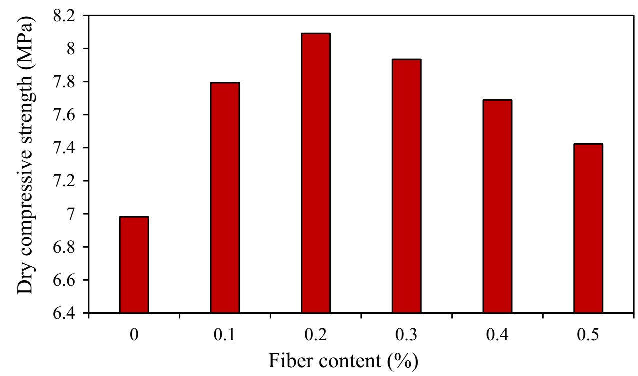

Fig. 8. Variation of dry tensile strength of CEB with fibers.

because increasing the fibers content led to a decrease in the mix content. Similar results are obtained by other researchers [9,19].

3.2. Capillary absorption test

Some researchers indicate that the absorption coefficient (Cb) can provide a best idea on the performance of CEB [35] as water is the first enemy of earth-based construction materials. In Fig. 7, the variation of absorption coefficient as function of fiber content is plotted. It is observed that the absorption coefficient ncreased with the increase of fiber content. In comparison with unreinforced blocks the absorption coefficient of 0.5% fiber-reinforced blocks was increased by 71%. These findings are in agreement with that showed by Danso et al. [36]. They reported that the addition of the fibrous waste increases the absorption. This behavior is justified by many authors [33–35]. Therefore, this behavior can be explained by the fact that incorporating of fibers creates more voids by the generation of pathway between soil particles and also by the cellulose of the fibers. Even though, this is increase in water absorption, it should be noted that this material is considered as weak capillary absorption as per NF XP 13-901[33].

3.3. Compressive strength

The variation of compressive strength of CEB according to the effect of change in fibers content is illustrated in Fig. 8. Strength results for cement-stabilized fiber-reinforced CEB are characterized by peak value 0.2% then further a decrease in strength is observed after the optimal values. This behavior is mainly attributed to the presence of fibers. Once fibers are incorporated, they support some part of the applied load which increase friction between matrixes. This what lead us to increase the contact forces between soil particles. It has reported in literate [8] that fibers when associated with soils, they create an additional cohesion in the composite and improve thereby the performance of earth based materials. The decrease in strength of cement-stabilized fiber-reinforced CEB after the optimal fiber content due to increase fibers create more voids which reduce the strength [34,37].

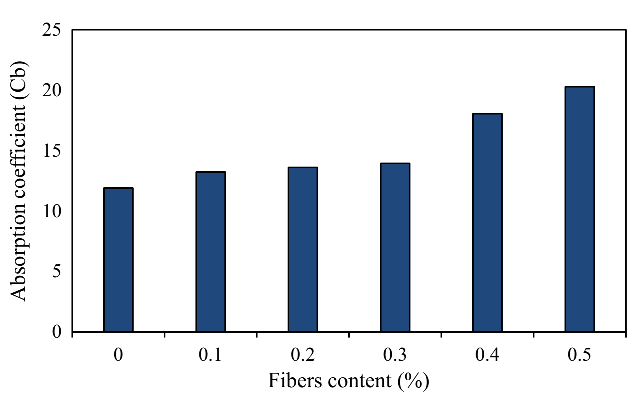

Fig. 7. Capillary absorption of CEB with fibers effect.

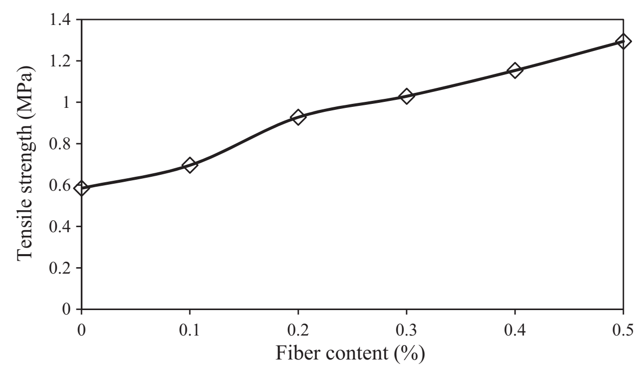

Fig. 9. Variation of tensile strength of CEB with fibers.

3.4. Tensile strength

The effect of change in the fibers content on the tensile strength of CEB is illustrated in Fig. 9. From the results it can be noted that the inclusion of Sisal fibers in the CEB will regularly increase the tensile strength. The highest tensile strength value is recorded for 0.5% fibers content while the lowest is observed for unreinforced CEB. These results can be explained by that the fibers subjected with tensile stresses can improve the adhesion between the fibers and the matrix. This finding is in agreement with that obtained by Millogo et al. [13]. In other study, Abd El Megeed Kabasy Mohamed [38] reported that the incorporation of 1% hay fibers may improve the tensile strength of fiber-reinforced of clayey soils.

4. Conclusion

In this work has an eco-friendly construction material produced with mixing clay and brick waste. The blocks were stabilized with combined effect between sisal fibers and cement. According to the obtained results, these conclusions can be drawn:

- The increase of sisal fibers content reduces the density of CEB due to low density of fibers.

- The capillary absorption of the blocks increases with increasing of fibers content but the results obtained are already satisfied the limit recommended by NF XP 13-901 further the material is considered as poorly absorbing of water by capillary action.
- Cement-stabilized fiber-reinforced CEB, curves are characterized by peak strength then further a decrease in strength is observed after the optimal values, this decrease is caused by the presence of fibers which increase the porosity in the blocks compared to unreinforced blocks.
- In term of tensile strength, it is observed that is regularly increased as the fiber contents is increased in the mix.

In addition to that, it is recommended to investigate other parameters such as fiber length, also it is highly recommended to study the thermal efficiency of this material in buildings.

CRediT authorship contribution statement

Yacine Labiad: Resources, Investigation, Visualization. **Abdelaziz Meddah:** Conceptualization, Methodology, Writing – review & editing. **Miloud Beddar:** Resources, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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