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Characterization of a stabilized earth concrete and the effect of incorporation of aggregates of cork on its thermo-mechanical properties: Experimental study and modeling

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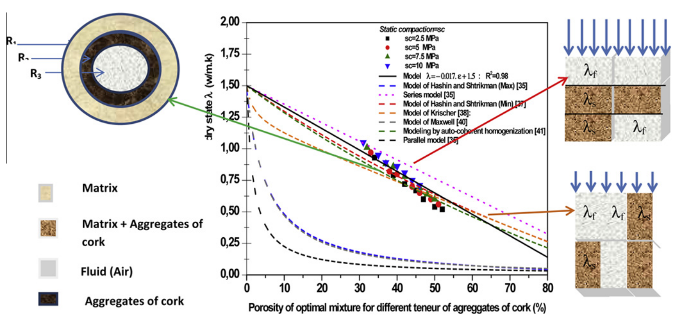
HIGHLIGHTS

- Effect of aggregates of cork on the thermo-mechanical properties of CEB.
- Mechanical strength decreases but acceptable with increasing content of cork.
- Some analytical models are used for comparison of experimental results.
- The energy consumption for thermal comfort can be reduced.

GRAPHICAL ABSTRACT



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ABSTRACT

In this paper, mechanical and thermal properties of compressed earth blocks stabilized (soil–sand dune–cement) with and without aggregates of cork have been studied, with the use of some models that predict thermal conductivity for comparison of experimental results. The first part highlights the influence of the percentage by weight of cement and of sand dune on the maximum dry density, optimum moisture content and mechanical resistance. The results showed that mass content of 30% sand dune and 12% cement significantly improves these properties more in the wet conditions than dry, and therefore gives the optimal mixture (58% of soil–30% of sand dune –12% of cement). However, the composite materials used for building must present sufficient mechanical strength to be suitable for constructions. For that the optimal composition has undergone a static compaction (2.5–5–7.5–10 MPa) thus showing further improvement on the same properties. Incorporating the aggregates of cork (3/8) in the optimal mixture, improves significantly the thermal performance with little influence of compaction, while remaining within the range of acceptable strength. Lastly the study was extended to the search for theory capable of predicting the effective thermal conductivity of a dry blend considered like a two-phase system, which shows that linear model and some theoretical models give the best concordance with experimental results.

1. Introduction

Environmental concerns can discover the qualities of earth material. Its use is not involved in the depletion of resources and increased pollution (water, air, soil) and waste, biological changes.

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This material has become more and more economically competitive because of raw material availability and simplicity in the production process. Soil stabilization with hydraulic binders was started in 1917 and that many researchers focused their research in this direction [1–13]. The hardening of the soil is generally affected by the cement hydrates in the presence of water to form complex carbohydrates. The cement induces the consolidation (creation of a skeleton) that coats the grains and opposes the movement of the material. The main reactions taking place in the consolidation of the cement itself between the stabilizer and the sand fraction of the earth. However, side reactions are observed between the stabilizer and the clay fraction of soil. The clay acts on the effectiveness of the stabilization process and modifies the mechanical behavior of the earth. Several studies have investigated the behavior of stabilized earth blocks facing a number of physical constraints. And the effect of the type of cement that presents a level of reactive silica, plays a vital role in reducing the porosity and consuming a portlandite generated by the selected cement, This is confirmed by [14–16], different hydrates responsible for the hardening of the cement that bind the clay particles to form a solid block [1,17,19], and also the mechanical strength increases with the gradual addition of cement [7,8]. A study by Guettala et al. [20] shows the effect of the mass of sand and a content of 30% affects positively the mechanical strength for 30% of sand in dry medium and a 36% in wet. Venkatarama Reddy et al. [21] also show that the resistance changes significantly with the dry density, and that it operates independently of the content of water and cement; But many authors restrict the dry density in the range of 1500–2000 kg/m^3 and determined according to the standard procedure as ASTM C 140 and BS 1924-2 (1990) standard and others [1,15,22,23]. The compressive strength and the dry density, change with the increase of the static compacting [1,17,18]. One of the major concerns of a designer is to provide a well-insulated building providing comfort at the least cost to the user both in winter and summer. Bahar et al. [1] proclaimed in a study that the addition of cement and sand may slightly decrease the conductivity of the brick; however; moisture increases the thermal conductivity of the sample relative to its dry state [1,17]. In the same way Meukam et al. [24,25] show that the thermal conductivity significantly increases with the content of the water in mixture. Indeed, increased the wetting of materials, results a replacement the pores progressive of air by the water. Several studies have been made on the integration aggregates of cork in cement and plaster to obtain a best thermally insulating [26–30]. Based on the experiences reported by Castro et al. [31,32], the concrete blocks containing cork exhibit a reduction in the thermal conductivity rate of 45% relative to the blocks without cork. Panesar et al. [33,34], also show that the thermal conductivity is affected by the bulk density of the composite of cork that provides additional volume in void. The apparent thermal conductivity of porous material depends on many parameters; the thermal conductivities of the solid and fluid, the degree of porosity, the size, shape and distribution of the pores. The thermal study of a sample of porous materials requires good knowledge of the microstructure on the one hand and on the other hand has the analytical or numerical tools for processing data required. There are analytical models considered predictions tools developed to understand the heat transfer mechanisms in the multiphasiques middles. These should allow the incorporation of the microstructure (particle shape, the contact areas) and the microstructure (boundary conditions, porosity). Many analytical models are used to calculate the apparent thermal conductivity of materials biphasic according to the solid middle and fluid of the two present phases and also of their porosity and their compactness. The actual thermal conductivity of the medium and whatever the model used, is always between two extreme values, the lower bound (series model) is an environment where the vector density of heat flow is perpendicular to the layers and the upper bound (parallel model) corresponds to an arrangement of layers parallel to the direction of the density of heat flow. [35]. Bensenouci et al. [36] adopt a thermal model of a concrete pozzolan on two approaches by comparing the experimental results with those obtained by theoretical calculation. Some prediction models are used by many authors and generally are Hashin–Shtrikman [37] and Krischer and Kroll [38]. Willy and Soutwik [39] and Maxwell [40]; by homogenization self-consistent [41] and others. This paper therefore aimed to study the influence of the addition of aggregates of cork on the mechanical and physical properties after optimization of the mixture (soil–sand–cement) and their effects on the thermal behavior; a comparison of experimental results with some prediction models will be well studied by observing the correlation between the results.

2. Experimental program

2.1. Materials

The soil used in this investigation was sourced from the Djelfa region which was first passed through a 5 mm sieve before being characterized. Table 1 summarizes the characteristics of the soil used. Fig. 1 gives the grading curve of the soil used. Composite cement (CEM II/B) class 42.5 MPa with 35% to limestone fillers was used for the chemical stabilization of soil. The clinker is from the cement factory of M'sila. The chemical analysis of clinker shows that it is in conformity with standard NFP 15-301. The chemical and mineralogical compositions of clinker are presented in Tables 2 and 3, respectively. The sand used was fine sand dune passing a 0.63 mm sieve from the Djelfa region. Table 4 also shows some physical characteristics of the studied sand dune. The grading curve of sand dune is given in Fig. 1. Cork granules from waste in sawing plate's compressed cork at the factory located in Jijel region, these wastes are then separated according to the different sizes using sieves. Table 5 shows some characteristics of the studied cork granules. The grading curve of the cork granules 3/8 mm is given in Fig. 1. The water is drinking water that contains little sulfate and having a temperature of 20 ± 2 °C. Its quality conforms to the requirements of NFP 18-404 standard.

2.2. Testing method, proportions of mixtures and the specimens preparation

An experimental program was carried out to studying in parallel the effect of different percentages of sand dune 0%, 10%, 20%, 30%, 40%, 50%, 60% and 70% by mass relative to soil and the influence of the chemical stabilization by cement addition 0%, 2%, 4%, 6%, 8%, 10% and 12% by mass relative to soil on the physic-mechanical properties of the various mixtures. We have prepared fifty-six formulations without compaction and without the incorporation of the aggregates of cork. The details of the mixtures proportions are given in Table 6. After this we have determined the optimal composition (soil–sand dune–cement). Subsequently, we studied the influence of the mechanical stabilization by static compaction for four levels of applied stresses 2.5, 5, 7.5 and 10MPa on the mechanical properties, maximum dry density and thermal conductivity the mixture already optimized in the first part, well as the effect of the curing methods(dry-humid) on the mechanical properties and thermal conductivity of optimized mixture. Finally, we evaluated the effect of the incorporation of the mass contents of the cork granules 2%, 4%, 6%, 8%, 10% and 12% relative to soil

Table 1
Characteristics of the soil used.

Property		
Atterberg's limits	Liquid limit W_L	70.4
	Plasticity index I_p	43.2
Grain size distribution	Gravel (>4.75 mm) (%)	2.3
	Sand (0.074–4.75 mm) (%)	6.4
	Clay and silt (<0.074 mm) (%)	91.3
Chemical characteristics	Iron oxide-alumina (%) (Fe_2O_3–Al_2O_3)	14.6
	Carbonate $CaCO_3$ (%)	33.0
	Chloride NaCl (%)	0.15
	Sulfates $CaSO_4$ (%)	0.20
	Insoluble residue IR (%)	42.2
Normalized Proctor test	Optimum water content (%)	9.0
	Maximum dry density (kg/m^3)	1680
Sand equivalent	By piston test (%)	14.8
	By sight (%)	17.6