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Drying, cracks and shrinkage evolution of a natural silt intended for a new earth building material. Impact of reinforcement

Joanna Eid [a,*], Saïd Taibi [a], Jean Marie Fleureau [b], Mahdia Hattab [c]

[a] Laboratoire Ondes et Milieux Complexes CNRS UMR 6294, Université du Havre, 53 rue Prony, 76600 Le Havre, France
[b] Laboratoire de Mécanique des Sols, Structures et Matériaux CNRS UMR 8579, École Centrale de Paris, Grande Voie des Vignes, 92295 Châtenay-Malabry, France
[c] Laboratoire d'Etude des Microstructures et de Mécanique des Matériaux, CNRS UMR 7239, Université de Lorraine, Ile du Saulcy, 57045 Metz cedex 01, France

HIGHLIGHTS

- Study treats natural silt constituting new raw earth concrete patented.
- Relation between suction and water content were established.
- Tensile resistance was deduced from the corresponding suction value.
- Strain evolution was discussed: local heterogeneity causes crack appearance.
- Adding reinforcement to natural silt reduces crack ratio by a factor around 10.

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ABSTRACT

Series of drying tests are carried out on natural silt intended for the preparation of new raw earth concrete. This technique is different from rammed earth. The study treats the drying of various formulations of the natural silt with and without reinforcement. No binders were added to highlight the impact of reinforcement. Global and local deformation around a single crack are analysed using image processing. Adding reinforcements to natural silt reduces the percentage of cracking by a factor around 10. The suction is derived from water content corresponding to crack appearance and correlated to the ultimate resistance of the material.

1. Introduction

Natural raw materials such as earth, chalk, lime or gravel were the most common material used by our ancestors. They were used specifically in building construction technique. Nowadays, ecology and economy of energy are the most common problems of our 21th century. It is therefore necessary to adopt new construction techniques that use new materials as raw earth concrete.

Raw earth is the basic material of raw earth concrete mixed with low percentage of lime and cement. A new construction material called "Cematerre" based on raw earth was developed and patented by a company with the same name. It is used to produce load-bearing elements for the construction of simple three-storey buildings (ground floor and two upper floors), solid walls and partition walls. Compared to traditional rammed earth building methods, this new material is not compacted and it is cast into formworks as classic concrete. The advantage of this new technique is that it gives an industrial type of cadence. Several linear meters can be cast in a single day as in the case of conventional concrete. It takes 1 h/m^2 instead of 6 h/m^2. Moreover, mechanical strength is 6 MPa – six times stronger than traditional rammed earth. This earth building material is composed of 86% raw earth, as well as lime, cement and flax fibres. It is manufactured in-situ in the same way as classical concrete. It is poured into wall forms directly and kept to dry like cement concrete. However, this construction technique has several pathologies, including cracking due to drying. This phenomenon is induced by the presence of fines in the composition of the natural silt.

Drying is defined as the drain (loss of water) through evaporation. As explained by Terzaghi et al. [19] the loss of water

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* Corresponding author. Tel.: +33 648629147, +33 235217134.
E-mail address: joanna.eid@doct.univ-lehavre.fr (J. Eid).

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induces a mechanism of consolidation while the material remains saturated. This consolidation is visualised by the shrinkage of the material. Once the shrinkage limit is reached, the saturation of the material decreases and the invasion of air begin. This is the beginning of crack appearance [18]. Drying cracks are mainly tension cracks. Soil that is gaining strength during drying, develops a constraint which induces cracking [13]. The drying cracks are also called "shrinkage cracks". The appearance of cracks through drying occurs when the tensile forces which oppose the withdrawal exceed the tensile strength of the soil. This mechanism apparently simple, leads to many questions concerning the initiation and propagation of crack networks.

Several studies have attempted to explain the phenomena of cracking by drying using image processing. Unidirectional drying tests were performed by different authors ([1,2,9,10,12,15]). Lecocq and Vandewalle [10] carried out an experimental study on a clay blade long and narrow. Cracks divided the clay blade into small segments perpendicular to its length. Peron et al. [15] demonstrated the effect of the roughness of the support on the appearance of cracks. Shrinkage is accompanied by cracks if the support on which the samples lie generates friction. Indeed, this friction gives rise to tensile stresses in the sample in response to displacement induced by shrinkage. When in a point the tensile stress reaches the value of the ultimate tensile strength of the material, rupture occurs at this point.

Further work studied the propagation of cracks in a two-dimensional field. Tang and Cui [17] studied the effect of temperature on drying using image analysis technique. They estimated the shape of the cracks that appeared. They studied the variation of cracked area, as a function of the water content of the material. Wei [20] studied the field of surface deformation of the clay during drying using an image correlation technique and showed that, in a first stage, the cracks appear when the tensile strength is reached locally, and then the cracks propagate and bifurcate under the effect of the shear stresses that develop along the crack.

The study of drying cracks and specifically their depth has been the subject of growing attention in recent research. Marcelo et al. [11] presented the use of a 2D laser device coupled to a motion controller (which allows scanning of the total surface of a soil subjected to drying) and an electronic balance (for measuring the loss of water over time). This technique can determine the vertical as well as longitudinal and transverse shrinkage, and the depth and width of cracks.

In this paper the authors discuss the drying behaviour of a raw earth material, the natural silt without binders, in order to highlight the impact of reinforcement on minimising the percentage of crack. Two independent experimental techniques were done: the drying–wetting paths and the 2D samples drying. Drying–wetting paths were performed in order to identify the behaviour of the material while he is drying or wetting. The understanding of this behaviour allows establishing a relation between water content and suction. In 2D samples, drying process causes, in a first stage, a homogenous shrinkage and secondly when the water content decreases enough, local strain heterogeneity causes the onset of a network of cracks that spreads.

The first part of the paper treats the behaviour of natural silt during drying. Before the onset of the fracture network, the authors track the field of deformation in the material. And then when the network of cracks appears they analyse their openness, their orientation according to the water content and the distribution of strains around the crack.

The second part of the paper deals with the possibility to minimise this cracking by adding reinforcements that can take some of the mechanical efforts induced by shrinkage. A relation is then established between suction and water content at crack occurrence.

2. Materials and methods

2.1. Materials

The used materials are natural silt retrieved from earthmoving works and two types of reinforcement: vegetable flax fibre and synthetic fibre mesh. The natural silt was chosen because it is a local material, abundant near the place of construction. Vegetable flax fibres are ecologic and abundant all over the world; in Normandy they represent a leading cultivation. Other fibres can be studied in furthers experiments. The synthetic fibre was used in order to make a comparison with the vegetable fibres. The mesh of the synthetic fibre is isotropic and homogenous contrary to the vegetable flax fibres.

2.1.1. Silt

Based on grading curves and Atterberg limits, the soil used is classified as a sandy loam SL(SM) according to the LCPC-USCS classification. Its properties are listed in Table 1.

The soil is initially dried and sieved to 4 mm, and then it is moistened to obtain a mud. This preparation consists to add an appropriate amount of water to a dry natural material, in order to obtain an average water content ranged between 22% and 25%. The slurry obtained is wrapped and left to stand. Once homogenised the water content is constant within the solid matrix.

2.1.2. Vegetable flax fibre

The used flax fibres are vegetable fibres extracted locally from the region of Normandy. In the domain of vegetable fibres, flax fibres offer top-of-the-range performances (Fig. 1). Their mechanical properties (density ρ, Young's modulus E, ultimate or failure stress σ_u and ultimate or failure strain ε_u) are listed in Table 2.

The fibres are cut to a length of 7 cm as used in construction with this earth concrete.

2.1.3. Synthetic fibre

The used synthetic reinforcement is a synthetic plastic mesh. Its total dimensions are 18 * 18 cm. Its density is equal to 84.3 g/m^2. The mesh has a rhomboidal shape. Its side is 8 mm and the diagonals are 13 mm and 10 mm (Fig. 2). It has very

Table 1
Silt properties [8].

VBS	0.5
W_L (%)	20
IP	6
Granulometry	
Fines content (<80 μm) (%)	35
Clay (<2 μm) (%)	0
Silt (2 μm to 60 μm) (%)	25
Sand (0.06 mm to 2 mm) (%)	67
Gravel (>2 mm) (%)	8
D_{10} (μm)	32
$C_u = D_{60}/D_{10}$	4.37
$C_c = \frac{D_{30}^2}{D_{60} * D_{10}}$	0.94

Fig. 1. Vegetable flax fibres.