Thermophysical characterization of earth blocks stabilized by cement, sawdust and lime

Azakine Sindanne S [1], Ntamack GE [1], Lemanle Sanga RP [1,*], Moubeke CA [1], Kelmamo Sallaboui ES [1], Bouabid H [2], Mansouri K [3], D'Ouazzane SC [4]

1 Groupe de Mécanique et des Matériaux, GMM, Département de Physique, Faculté des Sciences - Université de Ngaounderé B.P. 454 Ngaoundéré, Cameroon
2 Laboratoire de Mécanique et Matériaux, Faculté des Sciences, Université Mohammed V, Agdal, Avenue Ibn Batouta, Agdal, Rabat, Morocco.
3 Laboratoire des Signaux, Systèmes Distribués et Intelligence Artificielle (SSDIA) ENSET, Boulevard Hassan II Mohammedia, Université Hassan II Casablanca, Morocco.
4 Laboratoire de Mécanique, Thermique et Matériaux, LMTM, Ecole Nationale de l'Industrie Minérale, ENIM, B.P. 753 Rabat, Morocco.
* Corresponding Author: lemanlesanga@yahoo.fr

Abstract. Several buildings throughout the world are built with blocks of compressed and stabilized ground. These blocks do not commonly have the same thermal properties necessary for their use. If the incorporation of stabilizer in these blocks like lime or cement increases the mechanical properties, it is not the case for the thermophysical properties. In this paper, the evolution of the thermal properties of earth blocks according to the rates of stabilizer and their nature was discussed. The experimental method of "hot iron" was applied. Results indicate that thermal conductivity increases when percentages of cement and lime increase. However, it decreases when the rates of the sawdust increase. Moreover, thermal resistance decreases according to the percentages of lime and cement, and increases according to the percentages of the sawdust.

Key words: Earth blocks, stabilization, thermal conductivity, thermal resistance, cement, lime, sawdust.

1. Introduction

Earth blocks can be done using raw or cooked Earth. Nowadays, the technique of stabilization is used to improve the mechanical and physical properties of earth blocks (De Chazelles, 2011). The stabilization technique can be defined as all physical or chemical processes used to improve the characteristics of earth blocks, in particular its bearing resistance, its sensitivity and its durability (Meukam, 2004). Several construction techniques using earth as a raw material exist (for example: bauge, adobe, compressed earth brick, mud, earth-straw, etc.) (Plat, 1989). In warm regions such as Cameroon, Morocco and Yemen, earth block is used in the form of mud (Pignal, 2005). Nowadays, earthen construction has experienced a renewed interest thanks to the introduction of new techniques of preparation and scientific analysis. Such is the case of compressed earth blocks (CEB) mode. The CEB have a good mechanical resistance and a good thermal inertia. However this resistance is low when compared to that of other building materials. Therefore, they are stabilized by cooking either by addition of stabilizers, such as lime, cement or even by adding materials of vegetable such as straw or sawdust. In this paper, the thermophysical properties of compressed and stabilized earth block (CSEB) were determined. At first, some heat transfer modes and techniques of thermal insulation in buildings was presented. Next, the methods used to estimate the thermophysical properties of the CSEB were described. Finally an analysis of the experimental results of conductivities and measured thermal resistance was completed.

2. Materials and methods

There are three types of thermal isolation: interior isolation, exterior and integrated isolation (Binici, 2007). The estimation of thermophysical quantities of CSEB is an aspect that needs to be mastered by manufacturers. Among the many methods developed for the determination of these properties, the following principal methods can be cited: hot iron method (Rigacci, 2002); hot-

wire method (Castets, 1982); flash method (Parker, 1961) and guarded hot plate method (Khedari, 2005). In our work, the technique of hot iron, which has proven its efficiency, has been opted (Rigacci, 2002). Methods for the experimental identification of sources of heat, heat flux or thermophysical parameters require an instrument for measuring temperature in transient or permanent regime in specific points on the rear surface or prior samples (Fourier, 1988). The most commonly used contact measuring instruments are the thermocouple, Platinum and thermistor probes.

2.1. Description of the hot iron method

This method dwells on the use of a cylindrical bar of iron and a thermometer. The matter is to connect the iron to the sector and to introduce it at the center of the test piece. The iron must be isolated from the thermometer to reduce heat loss. Iron allows you to heat the tube and cause the rise in temperature in the thermometer. This technique measures the difference of temperature in the CSEB between the initial state and the state after heating. The evolution of the temperature depending on the time, that the tube heats up, can be expressed as follows (Rigacci, 2002):

$$\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} = \frac{1}{D}\frac{\partial T}{\partial t} \tag{1}$$

With the following boundary conditions (Nagasaka, 1981):

$$\begin{cases} \forall r, t \le 0, \delta T(r,t) = T(r,t) - T_0 = 0 \\ \forall t \ge 0, r = 0, \lim\limits_{r\to\infty}(r\dfrac{\delta T(r,t)}{\delta r}) = \dfrac{-Q}{2\pi\lambda} \\ r \to \infty, \forall t \ge 0, \lim\limits_{r\to\infty}(\delta T(r,t) = 0 \end{cases} \tag{2}$$

$$\delta T(r,t) = \frac{Q}{4\pi\lambda}\sigma(\frac{r^2}{4Dt})$$

If:

$$\frac{r^2}{4Dt} = \varepsilon$$

The following equation can be written:

$$\delta T(r,t) = \frac{Q}{4\pi\lambda}\left[\log(\frac{4Dt}{e^{\gamma}}) + (\varepsilon) + 0(\varepsilon)\right] \tag{3}$$

Taking into account the linear asymptote at long time, Eq 3 can be simplified to be:

$$\delta T(r,t) = \frac{Q}{4\pi\lambda}\left[\log(t) + \log(\frac{1}{\varepsilon t e^{\gamma}})\right] \tag{4}$$

λ : thermal conductivity ;

Q : flow of heat per unit length

e : the thickness of the test piece

r : Distance from the railway to the thermometer.

By standing in the case of a radial transfer in a semi-infinite medium, the formalism of quadruples in the Laplace domain allows the time long to approach the temperature δT by the relation (Oladele, 2003):

$$\delta T(r,t) = \alpha \log(t) + \beta \tag{5}$$

With $\alpha = \frac{Q}{4\pi\lambda}$

Thus, the identification of the slope α of the linear part of the thermogram $\delta T(\log(t))$ in equation (Eq 1) leads to estimate the thermal conductivity by the following relation:

$$\lambda = \frac{Q}{4\pi\alpha} \tag{6}$$

The thermal resistance can be calculated by the following relation:

$$R_{th} = \frac{e}{\lambda} \tag{7}$$

3. Results and discussion

For the stabilization of our specimens, three types of stabilizers: cement, lime and sawdust were used. A cement type CPJ 35 with a mechanical compressive strength of 23 MPa at 2 days and 50 MPa at 28 days was used. A high calcium lime made from a pure $CaCO_3$ limestone was used. Finally, sawdust used was dried, crushed and passed through a sieve of 0.5 mm.

3.1. Experimental Process

The different stabilizers were weighed using a precision scale of 0.1 g. For the preparation of test specimens, the laterites of the city of Maroua (Cameroon) were used. Before any compaction, soil samples were passed to the Proctor test that allows checking if the land is suitable for the manufacture of CSEB. After these tests, laterites were sprayed two days later and switched to hashing. After this operation, earth blocks were stabilized with the different used stabilizers, taking into account their mass percentage. Test specimens were made using a mold of dimension 29x14x9cm. The prepared specimens were dried in two phases for 28 days, either: 14 days under plastic cover and 14 days in the open air. After drying, 10 test specimens were conducted with the following compositions:

- Test tube 1 (E1): 100% of laterites + 0% stabilizer;
- Test tube 2 (E2): 96% of laterites + 4% cement.
- Test tube 3 (E3): 92% of laterites + 8% of cement.
- Test tube 4 (E4): 88% of laterites + 12% of cement.
- Specimen 5 (E5): 96% of laterites + 4% lime.
- Specimen 6 (E6): 92% of laterites + 8% lime.
- Specimen 7 (E7): 88% of laterites + 12% lime.
- Tube 8 (E8): 96% of laterites + 4% wood sawdust.
- Specimen 9 (E9): 92% of laterites + 8% of the sawdust.
- Specimen 10 (E10): 88% of laterites + 12% wood sawdust.

An iron that delivers a constant flow of 60 W was used. This iron can heat the tube and cause the evolution of the temperature in the thermometer. Before any experiment, the ambient temperature of the laboratory must be measured. Iron is holding off about 8 cm from the thermometer. Using the stopwatch, the evolution of the temperature in the thermometer was noted at regular time interval. For each type of specimen three measurements were conducted.

3.2. Determination of thermophysical characteristics

To estimate the conductivity and thermal resistance, the linear slope (α) from Eq. (1) was determined. This value will allow calculating the thermal conductivity ($\boldsymbol{\lambda}$) form Eq. (2). By applying the formula in Eq. (7), the value of the thermal resistance (R_{th}) can be deduced. The following curves have been obtained.

From the figures 1-3, it can be seen that the curve of the variation of temperature for CSEB containing sawdust remains below those of the other two stabilizers types. This implies that sawdust is slowing the evolution of temperatures in CSEB comparatively to cement and lime stabilizers. This slowdown can be explained by the gradual decrease of the values of thermal conductivities.

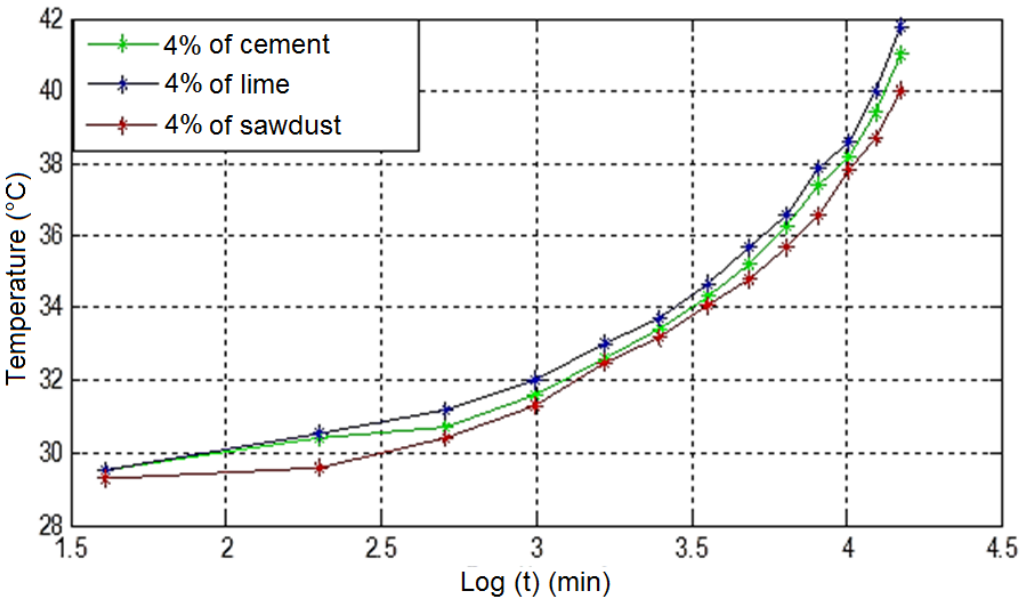

Fig 1. Experimental curves of the temperature variation in the CSEB at 4% versus log (t).

Figure 1 shows that the evolution of the temperature in cement and lime CSEB are close for the values between 1.5 and 2.25 of log (t). Above 2.25, the evolution of temperature in CSEB with lime is above those of the other two types of stabilizers. Therefore, it can be deduced that at 4% and for values of log (t) above 2.25, lime transmits more heat compared to CSEB with cement and sawdust.

In Figure 2, it can be seen that, for a dosage value of 8% of stabilizers, cement and lime are neighboring powers of heat transmission for values of log (t) between 1.5 and 2. In the meantime between 2 and 3.3, and unlike the case of stabilization at a dosage of 4%, lime shows more transmission of heat than CSEB with cement and sawdust.

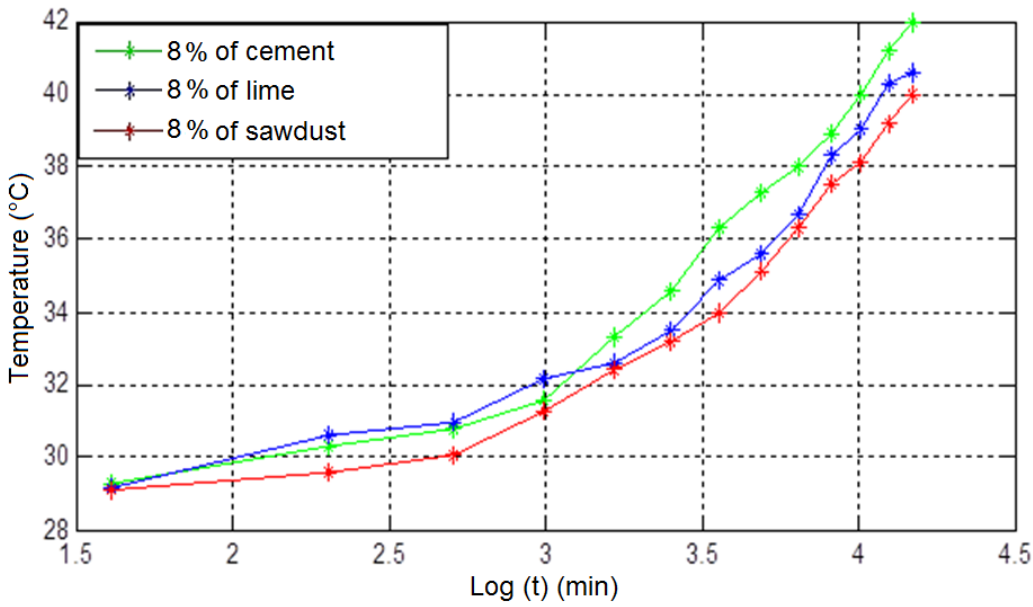

Fig 2. Experimental curves of the temperature variation in the CSEB at 8% versus log (t).

From the value 3.3 of log (t), it can be observed that the variation of temperature in the CSEB with cement is lower than that of CSEB with the two other types of stabilizers.

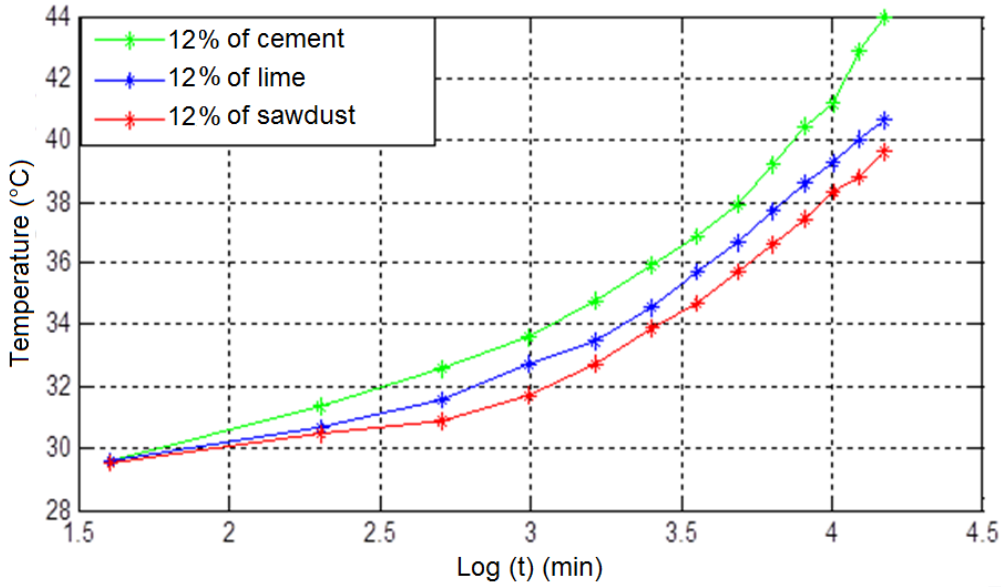

Fig 3. Experimental curves of the temperature variation in the CSEB at 12% versus log (t).

Figure 3 reflects the same observation, in which the variation of the temperature in the CSEB cement is above those of the other two stabilizers. Therefore, even if the addition of cement is suitable in order to increase the compressive strength of CSEB (Zine-Dine, 2000; Hakimi, 1999), the transmission of heat becomes important than to that in the presence of lime or sawdust.

From Figure 4, it can be observed that CSEB incorporating about 4 to 9% of cement, the thermal conductivities are low compared to lime and sawdust.

It can be also observed that the thermal conductivity increases with the percentage of cement and lime, but decreases with the percentage of sawdust.

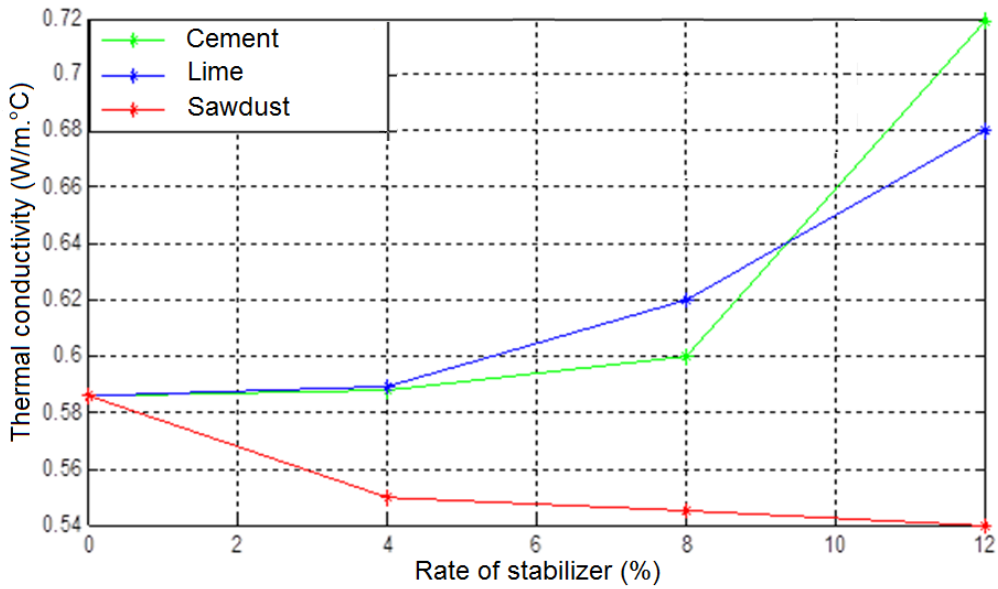

Fig 4. Curves of thermal conductivity depending on the rate stabilizers.

In the range of 0 to 4%, the curves of the thermal conductivity for CSEB with cement and lime are nearby. In the meantime, these stabilizers have almost the same power of heat transmission. However, the curve of thermal conductivity of CSEB with sawdust decreases with the increase of sawdust percentage. In the range of 4 to 9 % of lime CSEB transmits more heat than that with cement. Beyond this range, conductivity is reversed to be higher for CSEB with cement. For CSEB made with sawdust, the thermal conductivity decreases with the increase of the percentage of sawdust.

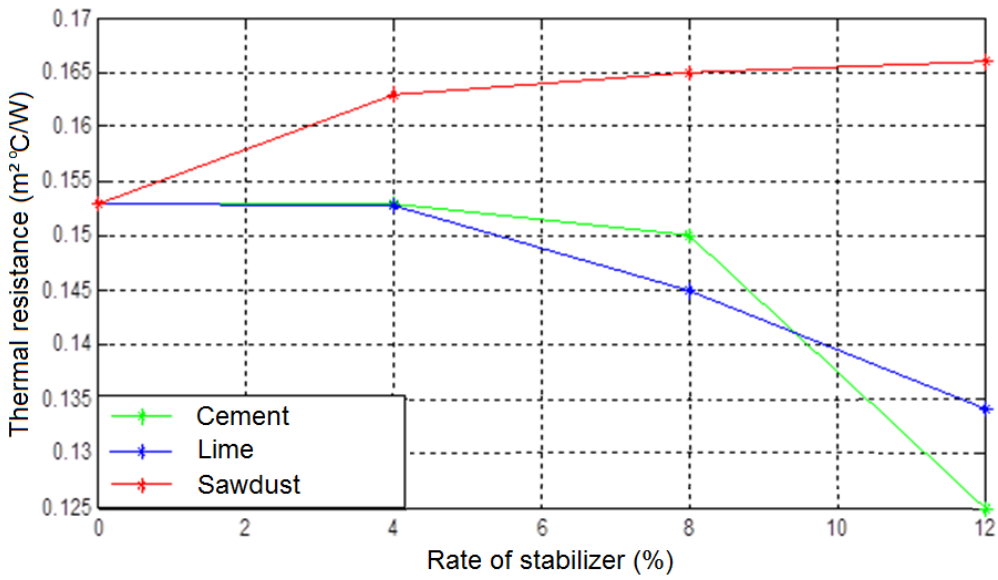

Fig 5. Curves of thermal resistance depending on the rate of stabilizers

The results of thermal resistance obtained, using Eq. (7), are presented in Figure 5. From this figure, it can be seen that CSEB made with sawdust shows higher thermal resistance than the other stabilizers (cement and lime). This can be explained by the alveolar structure of sawdust. It can be also seen that, from 9% of cement, CSEB with cement shows lower thermal resistance than sawdust and lime.

4. Conclusions

The aim of this work is to determine the thermophysical properties of CSEB with different stabilizers (cement, lime and sawdust). The incorporation of stabilizers was conducted in CSEB for different percentages: 4%, 8% and 12% for each type of stabilizer.

In the light of this experimental investigation, the following conclusions can be drawn:

- Thermal conductivities of CSEB increased with the increase of the percentages of cement and lime. The increase in thermal conductivities means that the thermal resistance decreases and consecutively, thermal insulation property of CSEB decreases.
- The use of sawdust as a stabilizer in CSEB decreases the thermal conductivity and increases the thermal resistance. As the increase in the thermal resistance is linked to the increase of the thermal insulation, CSEB made with sawdust are therefore recommended for construction, especially in the hot regions.

5. References

Binici H, Aksogan O, Bodur MN, Akca E, Kapur S (2007). Thermal isolation and mechanical properties of fibre reinforced mud bricks as wall materials. Constr. Build. Mater., 21(4):901-6.

Castets D, Iniesta H (1982) .Recherche d'une méthode de mesure des caractéristiques thermophysiques de la terre, matériaux de construction, TEF, ENTPE, Vaulx-en-Vellin.

De Chazelles CA, Alain K, Pousthomis N (2011). Les cultures constructives de la brique crue. Ecole Nationale Supérieure d'Architecture de Montpellier.

Fourier J (1988). Théorie analytique de la Chaleur, Firmin-Didot père et fils, Paris, 1822. Facsimile, Ed. Jacques Gabay, Paris.

Hakimi A, Fassi-Fehri O, Bouabid H, D'ouazzane SC, El Kortbi M (1999). Non-linear behaviour of the compressed earthen block by elasticity- damage coupling. Mater. Struct., 32(7), 539-45.

Khedari J, Watsanasathaporn P, Hirunlabh J (2005). Development of fibre-based soil–cement block with low thermal conductivity. Cement Concrete Comp., 27(1), 111-6.

Meukam P (2004). Valorisation des briques de terre stabilisées en vue de l'isolation thermique de bâtiments. Thèse de Doctorat, Université de Cergy Pontoise.

Nagasaka Y, Nagashima A (1981). Simultaneous measurement of the thermal conductivity and the thermal diffusivity of liquids by the transient hot-wire method. Rev. Sci. Instrum., 52(2):229-232.

Oladele I, Z (2003). Étude comparée des propriétés mécaniques et thermophysiques des briques en terre stabilisée au ciment et en argile cuite. Mémoire d'Ingéniorat, Université d'Abomey-Calavi, Benin.

Parker WJ, Jenkins RJ, Butler CP, Abbott GL (1961). Flash method of determining thermal diffusivity, heat capacity, and thermal conductivity. J. Appl. Phys., 32(9):1679-84.

Pignal B (2005). Terre crue, Techniques de constructions et de restauration. Eyrolles, Paris.

Plat P (1989). Influence du matériau sur le métabolisme humain - Colloque Construire en Terre, matériau noble à la conquête de l'avenir, Toulouse, France.

Rigacci A, Ladevie B, Sallee H, Chevalier B, Achard P, Fudym O (2002). Measurements of comparative apparent thermal conductivity of large monolithic silica aerogels for transparent superinsulation applications. High Temp.-High Press., 34(5) : 549-60.

Zine-Dine K, Bouabid H, El Kortbi M, Charif-d'Ouazzane S, Hakimi A, Hammoumi A, Fassi-Fehri O (2000). Rheology of walls in compressed earth blocks in uniaxial compression: study et modelling. Mater. Struct., 33(8):529-36.