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About drying effects and poro-mechanical behaviour of mortars

F. Skoczylas [a,*], N. Burlion [b], I. Yurtdas [a,b]

[a] Laboratory of Mechanics of Lille, UMR CNRS 8107, Ecole Centrale de Lille, Cité Scientifique, 59650 Villeneuve d'Ascq, France
[b] Laboratory of Mechanics of Lille, UMR CNRS 8107, Polytech'Lille-USTL, Cité Scientifique, 59650 Villeneuve d'Ascq, France

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Abstract

The drying of mortar and concrete generally affects their elastic properties and strength. Such property variations are of interest, since they affect the durability of structures designed with these materials. Previous studies, conducted on two mortars with different W/C ratio, showed that drying such material led to decreases in their elastic modulus and their Poisson ratio. Although generally attributed to micro-cracking, these decreases are nevertheless consistent with simple poro-mechanical effects i.e. transition from undrained behaviour toward drained behaviour. The main objective of this experimental study was therefore to state whether or not pore fluid pressure played a direct role in the variation of elastic properties measured on saturated or dried material. Poro-mechanical measurements of drained and undrained bulk moduli, Biot and Skempton coefficients were carried out. They actually revealed that poro-mechanical coupling effects could explain a part of the differences observed between elastic properties. Ethanol was chosen as the pore fluid to avoid possible unexpected chemical effects on the materials tested (often observed with water). To conclude about the saturation effects, a complementary experimental procedure was conducted in two steps: compression tests were performed on previously dried samples, which were then re-saturated with ethanol before being mechanically tested again. The results obtained are unambiguous and showed that poro-mechanical effects are not involved in the change in elastic properties. On an other hand, the major roles played by microcracks induced by drying and by capillary suction are highlighted: (a) The decrease in elastic properties, observed as drying occurs, is shown to be due to induced micro-cracking; (b) the increase in capillary pressure, brought about by drying, leads to an increase in the mortar failure strength.

Keywords: Mortars; Drying; Poro-mechanical behaviour; Elastic properties; Micro-cracking

1. Introduction

Durability of concrete structures is significantly reduced when they are cracked prior to any chemical or mechanical loading. As an example, if concrete shrinkage is locally prevented (by aggregates or structural effect), an early cracking of the material may take place which, as a result, will have negative effects on its mechanical properties and on its resistance to face physical and chemical attacks. Our main purpose here is to investigate how the drying and desiccation shrinkage influence the poro-mechanical behaviour of cementitious materials such as mortars. In fact, cementitious materials are submitted to different kinds of shrinkage (see in general [1–3]). Among these, one can point out the drying shrinkage that arises as free water is drained from connected porosity. This phenomenon results in capillary pressure (or suction) increase [2], surface energy variations [4] and disjunction pressure variations [5]. It is well known that these microscopic mechanisms lead to macroscopic material shrinkage [1,6,7]. Moreover there are observable consequences induced by drying which are less often described in the literature. On the one hand, the rise of capillary suction brings about increase in uniaxial compressive strength of mortars [8–11], concretes [12–15] and in triaxial compressive strength of mortars

* Corresponding author. Tel.: +33 3 20335363; fax: +33 3 20335352.
E-mail address: frederic.skoczylas@ec-lille.fr (F. Skoczylas).

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Table 1
Effect of drying on mechanical strengths and elastic properties

Mortars	Conservation mode	Young's modulus (MPa)	Poisson's ratio	Uniaxial compression strength (MPa)	Triaxial deviatoric compression strength (MPa) $P_c = 15$ MPa
Mortar $W/C = 0.5$	Saturated samples A	36,700	0.20	50.4	86.2
	Desiccation samples B[a]	34,300	0.18	64.1	104.4
	Dried samples C	31,800	0.15	61.6	111.5
Mortar $W/C = 0.8$	Saturated samples A	22,500	–	25.2	49.2
	Desiccation samples B[a]	22,600	–	32.7	72.3
	Dried samples C	18,600	–	26.5	72.5

Results from previous studies.
[a] The weight loss of these samples tested in uniaxial or triaxial deviatoric compression was between 4% and 5%. Young's modulus, Poisson ratio and uniaxial strength are the mean of three results. Triaxial strength is the mean of two results.

[10,18,19]. Increase in capillary suction leads to a compression of the solid skeleton which is similar to a "pre-stressing" of mortar acting like confining pressure. Therefore, there will be an increase in triaxial or compressive strength. On the other hand, material micro-cracking is due to desiccation shrinkage whose effect is either local or structural. A competitive effect occurs between both phenomena which explains results on compressive or triaxial strength presented in Table 1.

The structural effect mainly results from a non-homogeneous state of drying. This phenomenon is amplified if the material permeability is low. In brief, a non-homogeneous state of strain occurs in the sample which finally leads to micro-cracking if tensile strength is exceeded [1,2]. Rigidity differences between cement paste and aggregate is the main cause of the local effect. Since aggregates are acting as rigid inclusions, they prevent a part of the cement paste contraction, which leads to micro-cracking [20–22]. The latter strongly depends on the aggregates mean size, for instance the use of coarse aggregates (size over 6 mm) brings isotropic and diffuse micro-cracking [21]. Both effects can be reduced only if the relative humidity varies slowly and/or if very thin structures are considered which is generally out of practical cases [23]. Most often, and whatever the loading type (uniaxial or triaxial), elastic properties variations are observed after drying: decrease in elastic modulus of concrete [9,16,17] and mortar [8,10,11,18,24]. The decrease is also observed with Poisson's ratio [10,11,18].

Therefore, micro-cracking will have an influence both on elastic properties and on mechanical strength. Moreover, some consequences of the saturation state on strength have to be pointed out since an increase in the mean compressive stress applied to a porous material – preserved under 100% relative humidity – will lead to an over-pressure of saturating liquid. This effect, described below, is known as being the Skempton effect. Under a particular loading case (triaxial or uniaxial compression tests) this over-pressure may participate to further initiation and propagation of micro-cracks that would not be present if the material was dry. Hence, in the particular case of uniaxial test, this over-pressure brings about amplified lateral strain, thus leading to strength decrease. At this stage some questions appear: is there a saturation effect on elastic properties? Is there a strength decrease when a dried sample is re-saturated?

The investigation of possible drying effects on the poro-mechanical behaviour of a mortar as well as on yield and strength limits will be the main objective of this experimental study which is presented in two parts. The first part is devoted to a presentation of the materials studied, their cure modes and to a short review of influences of drying on their mechanical behaviour and properties. From this point, the second part describes the experimental program designed to investigate possible drying or re-saturation effects on poro-mechanical behaviour.

2. Analysis of previous experimental results and of possible poro-mechanical effects

2.1. Studied materials

The samples were composed of materials to obtain, on the one hand, two types of easily reproducible standard mortars and, on the other hand, mortars with mechanical properties close to those of a commonly used concrete. The only differences between both mortars were their Water by Cement ratio (W/C) being respectively equal to 0.5 (named mortar05 hereafter) and to 0.8 (named mortar08 hereafter). Other compounds were strictly identical – cement nature and proportion, aggregate nature and proportion (for more details see [19]). To ensure a complete maturation, these mortars have been preserved in water (at 20 °C) for six months, and then prepared according three distinct modes. A first series was preserved from desiccation by means of aluminium sheets, glued on sample surfaces (named *samples A* hereafter). A second series was let, during given variable times, into a desiccative atmosphere: 21 ± 1 °C and 45 ± 5% relative humidity (named *samples B* hereafter). Finally a third series was oven-dried at 60 °C to achieve a desaturated state – *i.e.* no more free water is present in the connected porosity (named *samples C* hereafter). The samples were 37 mm diameter and 74 mm length cylinders.

2.2. Review of previous studies on the drying effects upon uniaxial strength and elastic properties

The present study follows a large experimental program which has been undertaken on the mortars mentioned above. Numerous and important results were obtained and mainly concern uniaxial and triaxial compressive tests carried out on samples *A*, *B* and *C*, with various desiccation times for samples *B* [11,18,19]. The main results obtained on Young's modulus and Poisson's ratio variations as well as on uniaxial and triaxial strengths are reported in Table 1. They all are mean values of measurements performed on at least three different samples of each series *A*, *B* or *C* for the uniaxial tests and on two samples for the triaxial tests. Note here that the confining pressure used to perform the triaxial tests was 15 MPa. These results are evidence that drying leads to a decrease in elastic modulus which seems to be due to a damage of hydrous origin. Moreover, a decrease of Poisson's ratio for the $W/C = 0.5$ mortar can be put forward. Additionally, drying brings about an increase of uniaxial and triaxial strength. This may be a confirmation of a capillary pressure effect (suction) upon failure limits of cementitious materials. However, results obtained on limestone from Bourgogne (France) can be mentioned here. An experimental study has been carried out, by Lion et al. [25], to evaluate heating effects on poro-elastic properties of this calcite rock. Temperature increase was applied up to 250 °C in an oven and led to micro-cracking occurrence. The main results obtained put in light Poisson ratio decrease (as for mortar05) and a slight uniaxial strength increase (5–6%). On the one hand, Poisson ratio increase with micro-cracking, has often been related and theoretically explained for sandstones in [26]. On the other hand, the strength increase, measured for this limestone, could not be attributed to suction effect. It is therefore well-founded to assume capillary suction plays a major role for concrete and mortar but other phenomena may take place in the strength increase observed with drying, like variations of disjoining pressures or surface energy.

2.3. Poro-mechanical behaviour – isotropic material

As mentioned before, decreases in elastic modulus E and in Poisson's ratio simultaneously occur with drying (Table 1). Though essentially attributed to micro-cracking effect, these decreases are consistent with poro-mechanical effect. Testing a dried sample can be indeed regarded as a drained test (no pore pressure variation) while testing a saturated or (highly saturated) sample can be assumed to be close to an undrained test. A sample with a low permeability (which is the case as exposed further) and a short testing time would be in the required conditions to assume such an undrained case. According to Biot's theory, a saturated porous material is regarded as a superposition of two continua: solid skeleton and pore fluid. From a thermodynamics point of view, it is an open system which exchanges fluid mass with the exterior. The state variables are the strain tensor of the skeleton (ε) and the fluid mass change per initial volume (m). The associated thermodynamic forces are the total stress tensor (σ) and the pore pressure P. In fact, the pore pressure is an indirect thermodynamic force since the direct force associated with m is the enthalpy. However for experimental identification purposes, it is preferable to use pore pressure instead of enthalpy. For an elastic porous isotropic material, the state equations are for a saturated medium [27]:

$$\begin{cases} \sigma_{ij} - \sigma_{ij}^0 = 2G_b\varepsilon_{ij} + \left(K_b - \frac{2G_b}{3}\right)tr(\varepsilon)\delta_{ij} - b(P - P_0)\delta_{ij} \quad \text{(a)} \\ \text{or} \\ \sigma_{ij} - \sigma_{ij}^0 = 2G_u\varepsilon_{ij} + \left(K_u - \frac{2G_u}{3}\right)tr(\varepsilon)\delta_{ij} - bM\left(\frac{m}{\rho_0^{fl}}\right)\delta_{ij} \quad \text{(b)} \\ P - P_0 = M\left(-btr(\varepsilon) + \frac{m}{\rho_0^{fl}}\right) \quad \text{(c)} \end{cases} \tag{1}$$

where δ_{ij} is the Kronecker symbol. σ_{ij}^0 and P_0 are initial stresses and pore pressure. Eqs. (1a) and (1b) are equivalent and commonly considered as drained behaviour for Eqs. (1a) or undrained behaviour for (1b). They generalised Hooke's law for a porous material. K_b and G_b are respectively the drained bulk modulus and shear bulk modulus, b is the Biot coefficient, K_u and $G_u = G_b$ are respectively the undrained bulk modulus and shear bulk modulus, and M is the Biot modulus. Let us assume here that E_b (E_u) and ν_b (ν_u) are respectively the drained (undrained) modulus and Poisson ratio. It comes: $G_b = \frac{E_b}{2(1+\nu_b)}$ and $G_u = \frac{E_u}{2(1+\nu_u)}$.

Therefore, a mechanical test – like a uniaxial compression test – which leads to an increase of the mean compressive stress $\Delta\sigma_m$ will induce an increase in pore pressure. For a real undrained test, carried out on a poro-elastic medium, the relation between stress $\Delta\sigma_m$ and pressure ΔP is given by [27]:

$$\Delta P = B \cdot \Delta\sigma_m \tag{2}$$

where B is known as the Skempton coefficient.

Strains and stresses measured under undrained conditions allow Young's modulus E_u and Poisson's ratio ν_u to be deduced. They are higher than E_b and ν_b with which they are linked by the following relations [27]:

$$E_u = \frac{3E_b}{3 - (1 - 2 \cdot \nu_b) \cdot b \cdot B} \tag{3}$$

$$\nu_u = \frac{3 \cdot \nu_b + (1 - 2 \cdot \nu_b) \cdot b \cdot B}{3 - (1 - 2 \cdot \nu_b) \cdot b \cdot B} \tag{4}$$

Therefore a part of the differences observed on the elastic properties between dried and saturated samples could be simply due to differences between drained and undrained properties. Hence special tests, as described below, were carried out in order to validate this hypothesis or not. They have first consisted in measuring main poro-elastic properties – *i.e.* Biot coefficient b, bulk moduli K_b and K_u and Skempton coefficient B in order to evaluate if the differences between drained and undrained properties are consistent with those measured between saturated and dried material.

3. Poro-mechanical experiments

3.1. Choice of pore fluid used for experiments

One of the main difficulties that occur with poro-mechanical property measurements on cementitious materials comes from perturbative effects caused by the saturating liquid. For instance, the use of water often brings about dissolution and re-hydration which will act on the flow transfer and lead to sharp changes in permeability. Evidence of this lack of neutrality was brought about with preliminary permeability tests. Experiments were undertaken with gas (pure Argon), ethanol and water on a mortar05 sample (see [28] for the measurement techniques). It was found gas or ethanol permeability close to 2×10^{-18} m^2 and water permeability less than 10^{-19} m^2. Moreover the water permeability value was constantly changing during the test. As a consequence it is very difficult and time consuming to measure mortar poro-elastic properties with water as interstitial fluid. To avoid such physical–chemical effects, it was decided to proceed to experiments with ethanol as saturating liquid which has proven to be neutral towards mortar – compared to water [28]. However, since this liquid is more compressible than water, the undrained properties measured with ethanol will have to be modified in order to obtain the "water" undrained properties. The latter will be therefore compared with elastic properties measured on saturated sample.

3.2. Experimental device and tests performed

The main and most useful poro-elastic properties are derived from hydrostatic tests. Three kinds of experiments were carried out: drained and undrained hydrostatic loadings, and a test in which the confining pressure remains constant while the pore pressure is increased (or decreased). The cell, used for such experiments, is described in Fig. 1. It is a hydrostatic cell which allows level of confining pressure up to 60 MPa to be applied with the confining pump. The injection pump is used to control pore fluid pressure. Pressure transducers (not shown in the figure) are also placed close to the upstream and downstream sides of the sample to verify pore pressure homogeneity. Capillary tubes may be used to measure the injected fluid mass into the sample if necessary. Four strain gauges are attached to the sample surface, two for axial strains and two for lateral strains. As the material revealed to be isotropic (see [19]), the volumetric strain was directly calculated as threefold the mean strain obtained with the gauges. The material under testing is sealed into a Vitton® jacket.

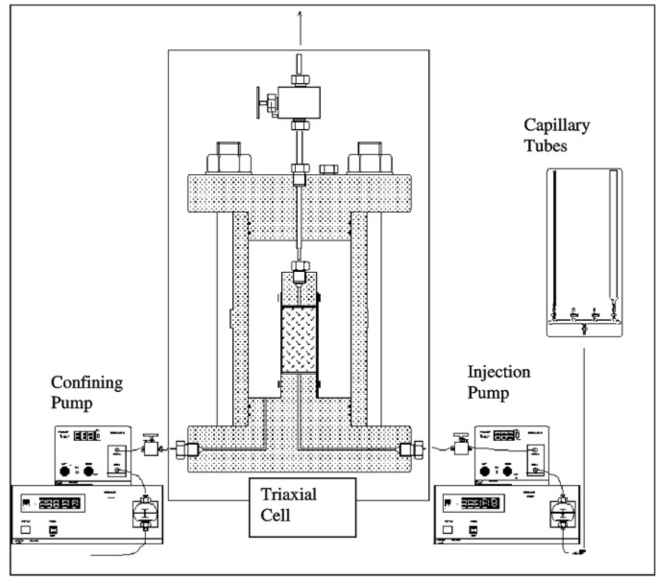

Fig. 1. Triaxial cell used for poro-mechanical experiments.

3.2.1. Drained test under hydrostatic pressure

Hydrostatic drained test is used to directly measure drained bulk modulus K_b of the skeleton. To measure such a property, interstitial pressure has to remain constant since confining pressure is increased (or decreased). Three samples (two samples of mortar05 and one mortar08) were tested with two different pore pressure values: $P_i = 0$ or $P_i = 1.5$ MPa. In the first case, samples are freely drained at both ends whereas, in the second case, small amounts of interstitial fluid have to be expulsed from the upper side of the samples in order to maintain P_i at a constant value.

Under such testing conditions, any variation of confining pressure ΔP_c would lead to volumetric strain $\Delta\varepsilon_v$ being from Eq. (1a):

$$\Delta\varepsilon_v = -\frac{\Delta P_c}{K_b} \tag{5}$$

3.2.2. Undrained test under hydrostatic pressure

After being saturated, samples are gradually loaded, in undrained conditions, with increasing or decreasing confining pressure ΔP_c. An increment of the latter induces instantaneous pore pressure variation ΔP_i and volumetric strain $\Delta\varepsilon_v$ which are recorded. According to poro-elastic behaviour, it comes from Eq. (2):

$$\Delta P_i = B\Delta P_c \tag{6}$$

in which B is the Skempton's coefficient, often much less than 1 for concrete. The use of Eq. (1b) leads to:

$$\Delta\varepsilon_v = -\frac{\Delta P_c}{K_u} \quad (7)$$

K_u is the undrained bulk modulus, which depends on concrete and fluid compressibility properties, it can be measured knowing $\Delta\varepsilon_v$ and ΔP_c. This "fluid-dependence" occurs for any "undrained property" such as Skempton's coefficient.

3.2.3. "Changes in pore pressure" test, matrix bulk modulus and Biot coefficient calculations and measurements

This test is used to measure the mortar matrix bulk modulus. As shown in Coussy [27], any loading step in which $\Delta P_c = \Delta P_i$ leads to a volumetric strain of the sample being that of the matrix – *i.e.* $\Delta\varepsilon_v$ (skeleton) = $\Delta\varepsilon_{vm}$ (matrix) whose bulk modulus K_m derives from Eq. (8) below:

$$\Delta\varepsilon_{vm} = -\frac{(\Delta P_c = \Delta P_i)}{K_m} \quad (8)$$

As a consequence, a test, in which the pore pressure is varied by ΔP_i while confining pressure remains constant, will lead to the modulus H to be measured with:

$$\Delta\varepsilon_v = \frac{\Delta P_i}{H} \quad (9)$$

From Eqs. (5), (8) and (9), it comes:

$$\frac{1}{K_m} = \frac{1}{K_b} - \frac{1}{H} \quad (10)$$

Once K_m is known, Biot coefficient can be derived from [27]:

$$b = 1 - \frac{K_b}{K_m} \quad (11)$$

3.3. Poro-mechanical tests: results and discussion

3.3.1. Results

As mentioned before, three samples were tested. As it can be seen in Fig. 2, which summarizes drained and undrained hydrostatic test results for the first mortar05, the material behaviour revealed to be perfectly linear and strain measurements given by the four gauges were virtually identical. This is first evidence that the poro-elastic theory applies for the mortars under discussion. Compared with mortar05, mortar08 appears to be highly compressible. This is consistent with its high porosity (24% compared to 15%) which is of great influence on K_b (and K_u). There is also evidence that a high water by cement ratio (W/C) has a major effect on the matrix compressibility (low K_m value) although it only includes non-connected porosity. Therefore it is macroscopic proof that cement paste deformability highly depends on W/C ratio – *i.e.* a high W/C ratio leads to a high amount of non-connected porosity that remains into cement matrix after hydration is completed. As a result and despite contrasted bulk moduli, the Biot coefficients are similar for both mortars (see Table 2). It can also be observed that the actual values of Skempton coefficient B are higher than the theoretical values, given in Coussy [27], which would be 0.14 for mortar05 or 0.23 for mortar08. The theoretical values can be derived from the following relation:

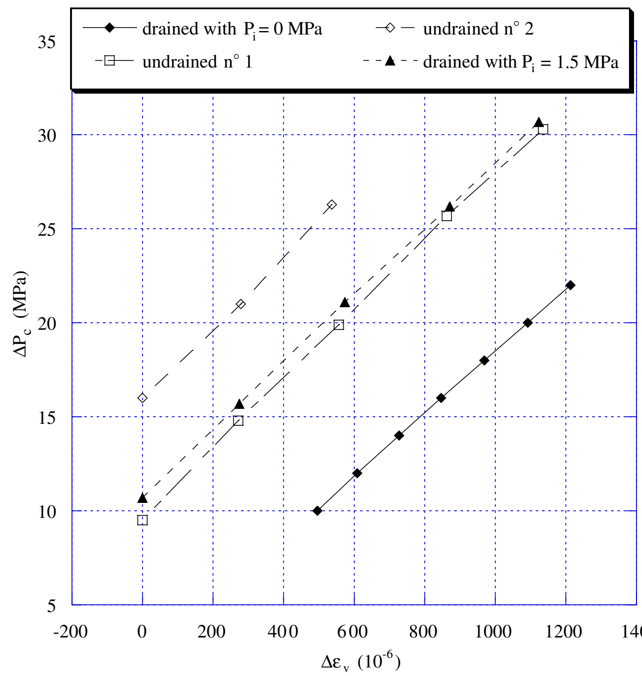

Fig. 2. First set of poro-mechanical measurements (hydrostatic loading) on the same mortar05.

$$B_{th} = \frac{\frac{1}{K_b} - \frac{1}{K_m}}{\phi\left(\frac{1}{K_{fl}} - \frac{1}{K_m}\right) + \left(\frac{1}{K_b} - \frac{1}{K_m}\right)} \quad (12)$$

K_{fl} is the liquid bulk modulus (800 MPa for ethanol and 2000 MPa for water). As K_{fl} is between forty to fifty times lower than K_m, Eq. (12) can be simplified into (13) below:

$$B_{th} \approx \frac{\frac{b}{K_b}}{\frac{\phi}{K_{fl}} + \frac{b}{K_b}} \quad (13)$$

3.3.2. Discussion for mortar05

Only results for mortar05 will be discussed in this part in order to evaluate undrained elastic modulus and Poisson ratio. The main reason of this choice is that this mortar is one order of magnitude less permeable than mortar08. Hence if elastic property differences come from poro-mechanical effects, they will be more visible with mortar05. Nevertheless, all the obtained measurements are given in Table 2.

Using Eq. (13), the Skempton coefficient B with water (B_w) can be estimated with:

$$B_w = B(\text{ethanol}) \cdot \frac{\frac{\phi}{K_{fl}(\text{ethanol})} + \frac{b}{K_b}}{\frac{\phi}{K_{fl}(\text{water})} + \frac{b}{K_b}} \approx 2 \cdot B(\text{ethanol}) \quad (14)$$

Table 2
Poro-mechanical measurements obtained for the both mortars

Sample	Porosity (%)	K_b (MPa)	K_u (MPa)	B	H (MPa)	K_m (MPa)	b
$W/C = 0.5$ no. 1	15	17,700	18,900	0.17	30,400	42,400	0.6
$W/C = 0.5$ no. 2	16	16,900	18,500	0.21	31,500	36,500	0.54
$W/C = 0.8$	24	6500	9100	0.27	11,150	15,600	0.58

Results from current study.

The poro-elastic relations (3) and (4) can be used to evaluate undrained elastic properties, they are with water as pore fluid:

$$E_u = \frac{3E_b}{3-(1-2\nu_b)bB_w} \approx 1.06E_b \tag{15}$$

$$\nu_u = \frac{3\nu_b + (1-2\nu_b)bB_w}{3-(1-2\nu_b)bB_w} \approx 0.21 \tag{16}$$

B_w is used in relation (15) since the elastic modulus of saturated sample was measured with water as pore fluid. The Poisson ratio is that of dry material – *i.e.* $\nu_b = 0.15$ (see Table 1). Results in this table show that the modulus E (saturated sample) $= 1.16 * E$ (dry sample). This is evidence that poro-mechanical effects (if present) are not sufficiently strong to explain the whole decrease in elastic modulus when sample is being dried. On the other hand, poro-mechanical effects could explain the observed differences between dry and saturated Poisson ratio as ν_u (undrained ratio) calculated with Eq. (16) is close to Poisson's ratio of saturated sample. A partial conclusion would be at this stage that poro-mechanical effects may represent a part of the differences between elastic properties of dry and saturated mortar.

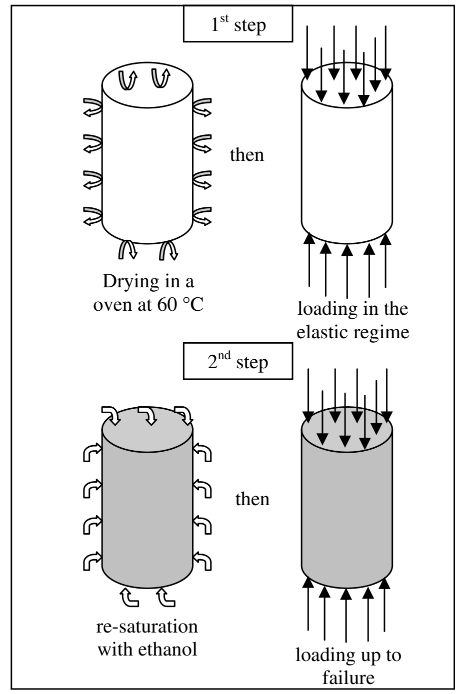

Fig. 3. Process design for testing dried and ethanol saturated sample.

3.4. Complementary experiment

Previous poro-mechanical study and results have proven that pore pressure coupling effects can explain a part of the differences in elastic properties (Table 1) between dry and saturated sample, differences which are often attributed to micro-cracking due to drying. To bring a definitive conclusion, at least for these kinds of material, a complementary experiment was carried out. The main idea was to perform a uniaxial compression test on a sample which had been previously dried. To avoid further micro-cracking, the stresses were applied to remain into the elastic domain. Stresses and strains, measured with four gauges can be used to obtain E_b, ν_b which are the "drained" properties. The sample was then re-saturated with ethanol under vacuum conditions, after the first compression test, and tested again until failure occurred with loading–unloading cycles (see Fig. 3). On the other hand, the new compression test allowed the measurements of E_{sat}, ν_{sat} and the comparison with the drained and undrained properties.

Two 74 mm length and 37 mm diameter cylinders were tested according to the method previously described. After drying until constant weight or after the ethanol saturation phase, they were loaded under uniaxial compressive stress up to 9 MPa. Typical results for both saturation states are depicted in Fig. 4: evolutions of axial stress versus lateral and axial strains are presented. They are virtually identical either for longitudinal or transversal strains. This means there is no obvious poro-mechanical effect, due to ethanol presence, that would have been induced by an increase in pore pressure. Nevertheless, if poro-mechanical effects had been present or active, results would have been (with the use of Eqs. (3) and (4) for ethanol): $E_{sat} = 33{,}000$ MPa and $\nu_{sat} = 0.19$ higher than $E_b = 32{,}000$ MPa and $\nu_b = 0.16$. This is obviously not the case. After these measurements, the test was extended, until failure, with loading–unloading cycles and Poisson ratio measurements. A comparison of the results obtained with dried samples or with samples saturated with water or ethanol is given in Fig. 5. This Figure represents Poisson's ratio variations for each saturation state with respect to the maximal stress reached at each loading–unloading cycle. One can notice that Poisson's ratio remains constant for low stress levels and starts to increase over a threshold known as "initial stress". Beyond, the effective Poisson's ratio continually grows: this can be related to the initiation, propagation

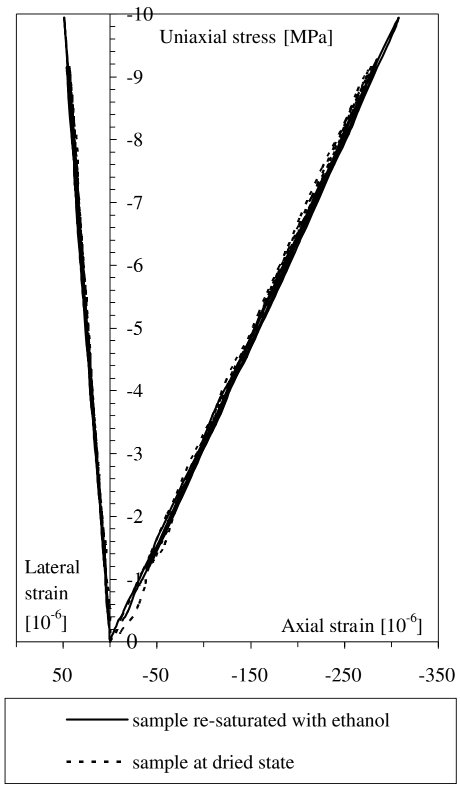

Fig. 4. Comparison of results obtained with dried or saturated sample.

and coalescence of microcracks. As for elastic parameters, Poisson's ratio values of ethanol saturated sample, varying with compressive stress, are consistent with those of dried samples. This is a confirmation of results previously mentioned (Fig. 2). Concerning failure stress, a clear difference has however to be pointed out: for the samples saturated with ethanol failure occurred at 54 and 48 MPa which are values close to the mean strength (50 MPa) measured with 15 samples saturated with water. For dried samples, the failure occurred at a mean value of 62 MPa. This phenomenon can be explained by three concomitant effects: a lubricating effect, local increases of interstitial pressure acting on micro-cracks opening and a decrease of capillary pressure level (or suction).

4. Conclusion

Cementitious materials are submitted to drying as soon as the relative humidity of their surrounding decreases. This drying induces well known macroscopic consequences such as desiccation shrinkage and superficial samples micro-cracking. However, on the one hand, increases of failure strength (under triaxial or compressive loading) are often observed when drying occurs. This is generally attributed to capillary suction effects. On the other hand, microcracks induced by drying lead to a decrease in elastic properties. This experimental study has shown some important points:

- Decreases in elastic properties of cementitious material are the result of micro-cracking due to a structural effect (differential shrinkage) and local effects (rigid inclusions). As these decreases could have been due to poro-mechanical couplings (at least partially), experimental procedures were carried out, with a neutral saturating liquid (ethanol), in order to confirm this possibility or not. Direct measurements of poro-elastic properties showed that a part of these decreases could be due to coupling effects between pore fluid and strains – *i.e.* transition from an undrained behaviour toward a drained behaviour. This is particularly the case for Poisson ratio.
- However a complementary experiment conducted on dried or ethanol saturated materials showed that there were no measurable differences in their behaviour.

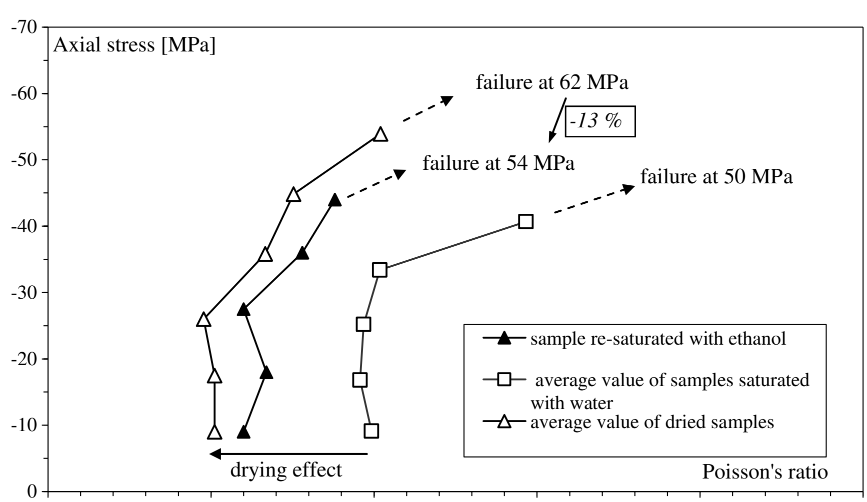

Fig. 5. Comparison of effective Poisson's ratio variations for dried and saturated samples. Results for dried and saturated materials are means results coming from previous studies on mortar05. Results with ethanol are mean values for two samples of mortar05.

- A clear effect of the saturating fluid presence was nevertheless recorded on the failure strength. This means that there is no significant macroscopic over pressure effect, modifying the elastic property values, and due to a coupling between volumetric strains and pore fluid at the highest saturation levels. This led us to think that the decrease of Young's modulus is only due to induced micro-cracks and not to the decrease in the amount of pore liquid. When saturated, the failure strength decreases (compared with the limits reached for the same dried mortars). This can be the result of local interstitial over-pressure and of capillary suctions decreases.

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