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COMPRESSIVE STRENGTH TESTING OF EARTH MORTARS

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Abstract: This paper discusses the compressive strength of earth mortars. The goal is to use these mortars for masonry construction. Although it is necessary to study the whole masonry behaviour, the scope of this paper refers to the mortar only, without taking into account the blocks. As with other masonry units, compressive strength is a basic measure of quality for masonry mortars. However, there is a great variety of methodology for determining their parameters and properties, such as different samples geometry, the way strains are measured and also the platen restraint effect adopted. The present paper outlines certain experimental devices used to determine compressive strength of earth mortars and tries to show their influence on the properties determined. Proposals for the future development of testing earth mortars are outlined.

Keywords: Earth mortar; Compressive strength; Constitutive law

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INTRODUCTION

Masonries can be constituted with dry joints or mortar joints. In dry joint masonries, the structure is not a continuum. However, these masonries behave in a monolithic way due to the friction among the masonry units (Villemus *et al.*, 2006).

In mortar joint masonries, the monolithic behaviour is guaranteed by mortars which transmit the loads among the blocks. Thus, these mortars must present a certain compressive strength value. Several researchers (Cincotto *et al.,* 1995), (Cavalheiro, 1995), (Gallegos 1995) and (Marzahn, 1997) also discuss the tendency and the need of a further capacity strain of masonry mortars, which would allow these mortars laterally expand further than the bricks because of lesser stiffness. The mortars therefore would absorb strain energy caused by these movements and avoid or minimize the appearance of cracks. Studying the whole constitutive law of mortars is thus needed.

This means that the compressive strength cannot be the only parameter taken into account to validate the use of a mortar in the construction of masonries. The mortar has to present other properties as a good adherence and tensile strengths. In fact, compressive tests can show or not the homogeneity of a mortar, from standard deviation of the results analysis.

The compressive strength of mortars for masonry construction has been deeply studied by several researchers. But there is no standard for compressive strength testing of earth mortars. It can be determined by several samples geometries. In the case of earth mortars, (Zine-dine, 2000) used the cylindrical geometry, (Venu, 1993) and (Walker 1997) used the cubic and (Bei, 1996) the prismatic one.

In this study, we have tested the methodology used for cement/sand mortars, where samples have dimensions 16x4x4 cm^3 and are first tested in bending and afterwards the broken pieces are tested in compression. The way strains are measured and the platen restraint adopted are also discussed in this study.

OUTLINE ABOUT EARTH MORTAR TEST PROCEDURE

Below we present an updated account of the influence of some parameters in the determination of compressive strength of earth mortars.

Platen restraint effects

We can carry out the compressive tests using a system with or without confinement. To eliminate the confinement, a fine layer of latex lubricated by silicone or Neoprene or Teflon is put between the plates of the test machine and the surfaces of the samples. The samples surfaces must be parallel one to the other in order not to move when charge is applied.

The system with confinement overestimates the compressive strength of the mortar, but the displacement measured by the piston of the press can be used for the calculus of strains, taking into account obviously that this displacement is not homogeneous.

On the contrary, if the neoprene layer is used, the compressive strength value is not overestimated but the displacement measured by the piston of the press cannot be used for the calculus of strains, because this neoprene layer is very compressible and so the displacement measured is the addition of the shortening of the neoprene and the sample together.

P'kla *et al.* (2003) assume that the system with confinement allows for an error of 20% on the compressive strength of earth mortar. They also note that it is interesting to compare the two methodologies and try to find a correlation between them in order to use only the system of confinement, due to its simplicity.

Influence of height/diameter relation in compressive strength values

The less the height/diameter relation is, the more the value of compressive strength will be, due to the platen restraint effects (confinement) which goes against security (P'kla, 2002). In other words, to use a height/diameter relation higher than 2 minimizes the error of measurement of the compressive strength in case of choosing an experimental system with confinement.

Therefore, it is rather better to use prismatic (imagine a circle inserted in a square) or cylindrical samples with height/diameter relation = 2, than using cubic ones.

Displacement measures by sensors of proximity and by the piston of the press

The piston of the press measures the displacement δ in the height H of the sample, so that the strain could be calculated by δ/H. But this strain calculated in this way is not reliable if the platen restraint effects exist. If so, the displacement measured is not homogeneous. But as discussed above, a system without confinement needs at least a different material as a layer between the press plateaus and the sample surfaces. This layer being compressible makes the displacement measured not be the real shortening of the sample. A good solution is the measurement of displacements in the middle of the sample without influence of confinement or of compressible layers in case of non-confinement. This can be done by sensors of proximity.

P'kla *et al.* (2003) used this system to measure homogeneous strains in their samples. The strain is calculated by making the subtraction between the values of each pair of sensors and then dividing this result by the distance between the targets.

Influence of kneecap

According to P'kla *et al*. (2003), if a kneecap system is not used in a compressive test, the samples should be submitted to a bending behaviour. The kneecap has the goal to centre the compressive load, avoiding any influence of surface defects of samples.

Influence of dry density

The dry density is also an important parameter which is proportional, for the same material, with the increase in the mortar strength (P'kla *et al.*, 2003). (Olivier, 1986) also observed this dry density report/ratio according to strength for the earth compacted blocks.

MATERIALS

Earth

An earth which came from a site named Tassin, close to Lyon, in France, was used. The nature of clay for the earth was determined by the "bleu" test and it is a little activate clay (see **Table 1**). Also, the grading curve of the earth was determined and is shown in **Fig. 1**. The earth was not enriched by clay, so this clay content is the normal one of the earth.

MORTAR SAMPLES PREPARATION

The procedure for the manufacture of the mortar was based on only one requirement: a good workability at sight.

The goal is to define an interval of water contents in which the mortar would be workable. Tassin earth was used with 17.5% percent clay and several cement contents (4%, 8% and 12%).

Sifting: To prepare the mortar, the earth was sieved in a 2 mm mesh sieve. This requirement is used to guarantee a good workability of the mortar in the joint between the blocks. For the manufacture of the blocks, on the other hand, the presence of gravels is acceptable with a size reaching even dmax = 2 cm.

Weighing: The precision used was always 0.01 g. Water content of earth: For stabilized formulations, the initial water content of earth was always determined since the cement content was calculated on the dry weight of the earth.

Mixture of the mortars: It can be carried out manually or using a mechanical mixer, but the best homogenization is obtained with the hand.

EXPERIMENTAL DEVICE

Influence of samples' geometry

Cylindrical and prismatic samples were used. The cylindrical ones with diameter = 7 cm and height = 14 cm. The prismatic samples had dimensions 30 × 8 × 6 cm^3 and 16 × 4 × 4 cm^3 and were tested in bending and afterwards their broken pieces were tested in compression. The first prismatic dimensions were used because the moulds already existed in the laboratory. The second ones were used in order to follow the standard rules (NF1015-11).

In the bending tests, for samples of dimensions 30 × 8 × 6 cm^3, the distance between the supports was 20 cm. All the other samples had dimensions 16 × 4 × 4 cm^3, with a distance between the supports of 10cm. These tests were carried out in agreement with the standard (NF 1015-11). The tensile strength in bending *f* of the samples was calculated according to the following equation **(Eq. 1)**:

$$f = 1.5\frac{Fl}{bd^2} \quad (1)$$

where F = charge of rupture. The parameters l, b and d are shown in **Fig. 2**.

Table 1 Nature of clay for Tassin earth

Majority	Minority
Illite	Kaolinite
Bleu activity = 8	

The displacement rate of the press was 0.005 mm/s. For the compressive testing, the samples coming from the bending tests presented dimensions 12 × 8 × 6 cm^3 and 8 × 4 × 4 cm^3. As we decided for not testing cubic samples, according to (NF1015-11), generally, only one broken piece was tested, because the other one did not have the dimensions required by a height/diameter ratio = 2.

Influence of mortars' cure

With regard to the cure, for all stabilized formulations, the mortar samples remained in a room of cure for a 28 days minimal period. Then, some mortar samples were placed in a drying oven (Tassin 17.5% clay + 8% cement – 4 samples) and all the others were left in the open air for drying. The purpose was to crush the samples with their weight stabilized. As the methodology in the open air has shown to be effective, it was then adopted by its simplicity, before all tests of simple compression.

For the non stabilized mortars, the samples stayed in the open air.

Influence of kneecap

A kneecap was fabricated with the same dimensions of samples section (see **Fig. 3)**. This small kneecap was fabricated to improve the centring of charge (Yurtdas, 2003).

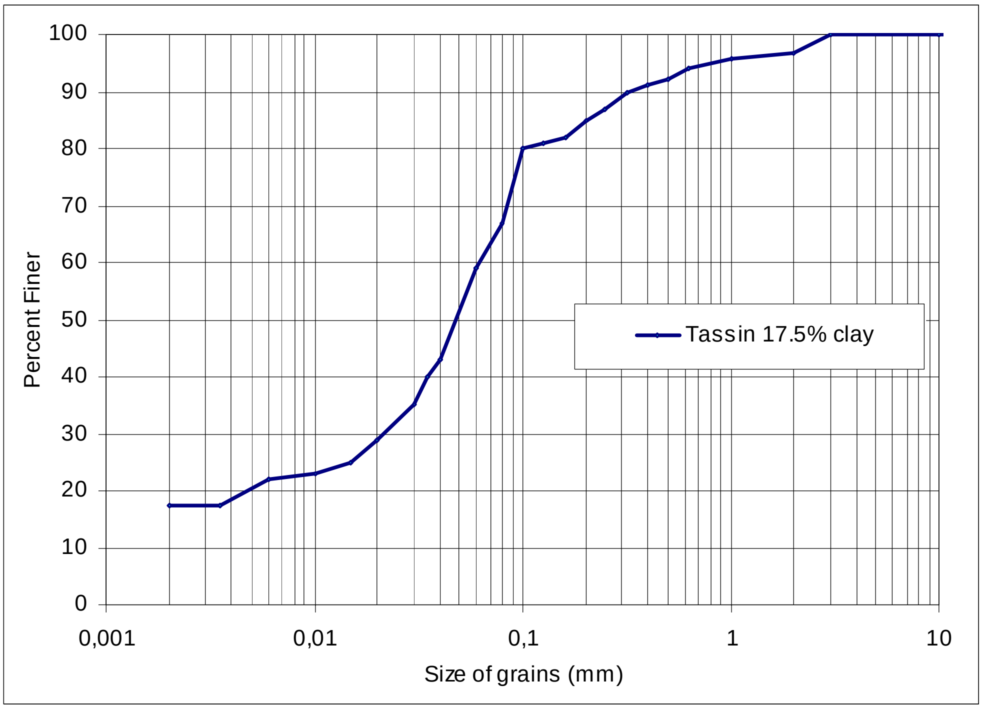

Fig. 1 Grading curve for T17.5% clay

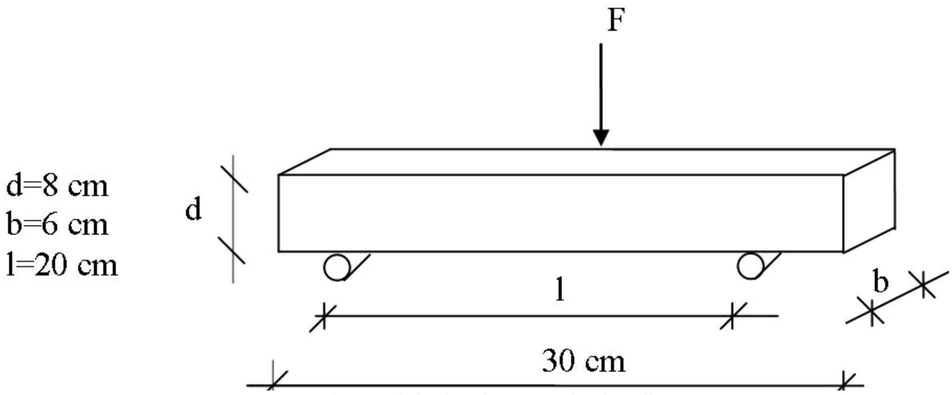

Fig. 2 Experimental device for a 3 point bending test.

Influence of platen restraint effects

For the crushing of mortar samples in compression, we tested the systems of confinement and non-confinement, with the purpose to evaluate their influence on resistance.

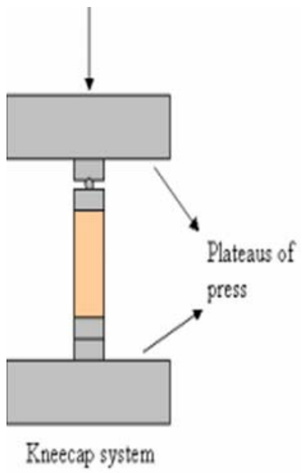

Fig. 3 Two types of experimental devices of kneecap

Non-confinement and confinement

We adopted the system of non-confinement in order to carry out homogeneous tests. The lubricated latex membranes used allowed us to obtain a more reliable lecture of strain without the influence of friction, but prevented us from obtaining with precision the average strain of the sample from the measurement of the displacement of the piston or lvdt. We thus decided to fix targets on the samples (see **Fig. 4**) in order to allow the acquisition of quasi-homogeneous displacements by sensors of proximity.

In a confinement system, the incremental position sensor of the piston would have been enough if we had considered the assumption of a homogeneous test. Nevertheless, we thought that the more distant we put the targets from the plates of the press the more reliable displacements values we would manage to measure, without the influence of friction. Thereafter, for all the other samples being tested in compression, with non-confinement and confinement systems, we used sensors of proximity to better evaluate their behaviour inside.

Sensors of proximity, conditioners and LVDT

Two types of sensors were used (see **Fig. 4**). One had 1.5 mm of measurement extension and the other 3.0 mm. The first one was placed on the bottom of the mortar sample and the other one on the top, where the displacement is larger. It is relevant to point out that on this press, it is the lower plate which is mobile.

The cables of the sensors of proximity were connected to conditioners which measured in volts the distance between the targets and the sensors of proximity. For the collecting of these data we used software named ESAM which transformed the electrical measurements into millimetres, i.e. in measurement of displacement. To guarantee a better measuring accuracy of the displacement of the press, we used a LVDT with an extension measure of 5 mm.

The displacement speed used for the compression tests was 0.01 mm/s.

Displacements Measures by LVDT

Compressive strength

The value of compressive strength σR is represented in **Fig. 5**. Even if the stress sometimes undergoes a hardening behaviour, compressive strengths were always associated to point A represented in this figure.

Dry density measure

Even if the samples had already the desired age (at least 28 days cure) for the rupture test, we wanted them to be drier. In this manner, we decided to put them in the open air as already quoted.

This stabilization is necessary in order not to underestimate the hardened strength of the mortar, because the presence of water inside the samples causes a decrease in strength.

SOME RESULTS AND ANALISYS FROM EXPERIMENTAL DEVICE DEVELOPMENT

Samples origin and geometry analysis

The compressive strengths given by cylindrical mortar samples were compared with those given by prismatic ones, for identical formulations. The height/diameter relation was 2 for both geometries. This result is shown in **Fig. 6**. Each point corresponds to the average of at least three points, which depends on the formulation concerned.

Fig. 7 shows comparison between samples directly tested in compression and samples tested in compression after the bending tests. It confirms the fact that samples coming from the bending tests underestimate strength. This could be explained by the formation of micro-cracks due to loading during the bending tests. In addition to the loading, the broken halves underwent a certain effort or vibration while sawing was realized (surfacing). This caused certain deterioration, especially in the sample edges. It was thus decided to use steel moulds having dimensions 8 × 4 × 4 cm^3 for the moulding of the prismatic samples to be tested in compression.

Platen restraint effects analysis

At the beginning of the test, for the non-confinement system, we observed that the sample moved horizontally and so the test had to be stopped. The movement occurred in fact because lower and upper surfaces of the samples were not perfectly parallel and also because the system of non-confinement was effective.

We finally decided to remove the silicone grease but to maintain the latex membrane in order to distribute the load and to decrease a little bit the friction between the plates of the press and the samples. We called this type of system confinement with latex.

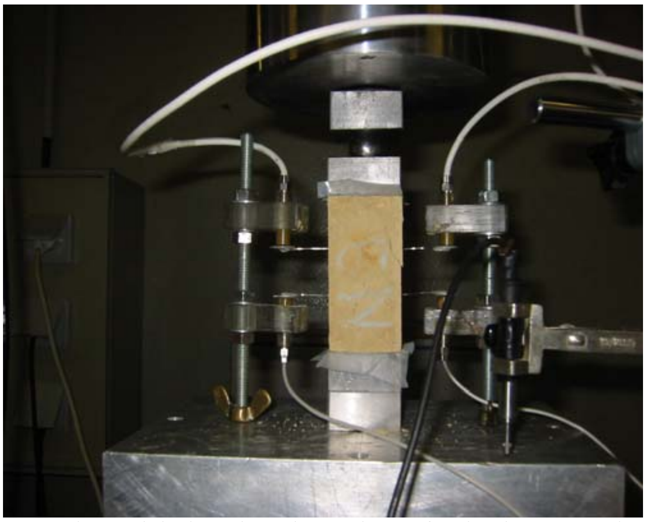

Fig. 4 Experimental device adopted as optimum for simple compression test.

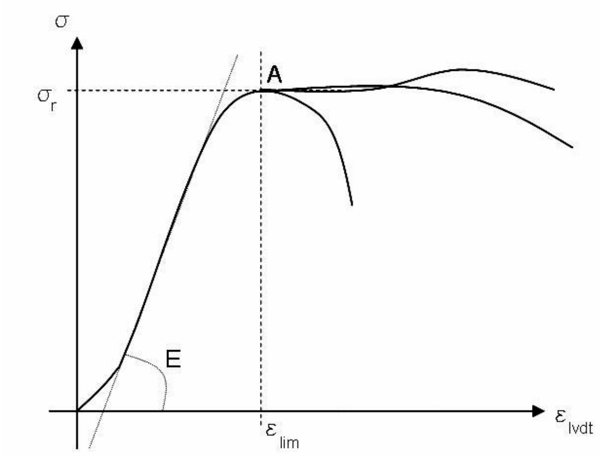

Fig. 5 Stress-strain curve – Strain measured by LVDT

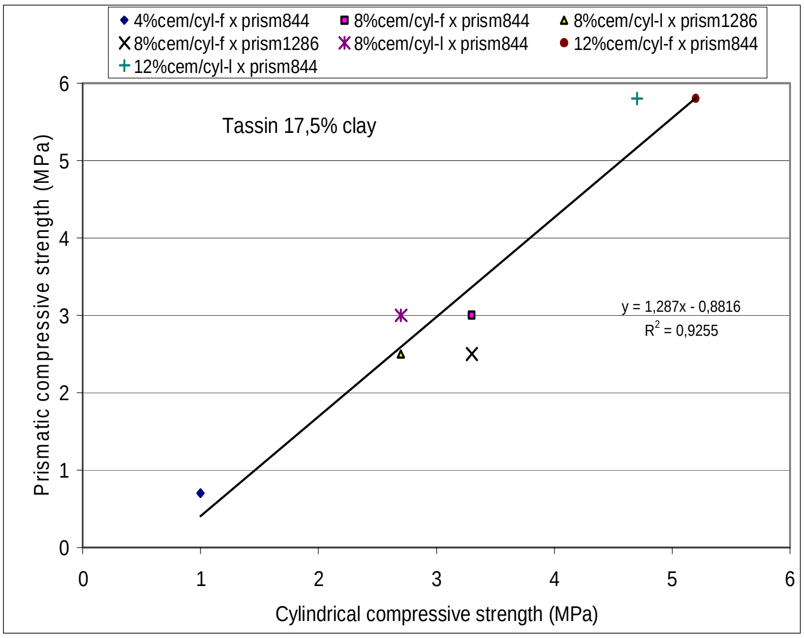

Fig. 6 Comparison between cylindrical and prismatic compressive strengths.

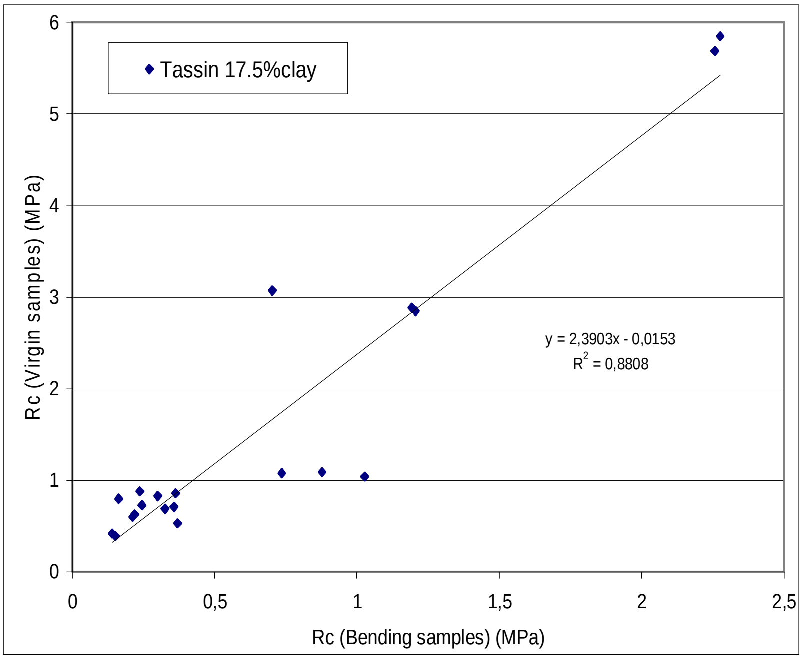

Fig. 7 Comparison between compressive strength belonging to virgin samples and others coming from bending tests – Tassin mortars (non stabilized and stabilized formulations).

Sensors of proximity analysis

In general, with samples presenting defined and invariable geometries, the experimental system with sensors of proximity functioned well. Nevertheless, some problems still happened, with the movement of the target (see **Fig. 8**). This movement of the target was caused either because the target was not well fixed in the sample or due to a cracking which caused its movement.

Anyway, the sensors of proximity enabled us to check that the deformation of the piston was not always representative of all the continuum of the sample.

For example, **Fig. 9** shows a good coherence among the curves of the piston and the sensors of proximity. It is seen that the elastic modulus of the mortar determined by sensors of proximity is much stiffer than the one determined by the piston.

Analysis and comparison between the systems Confinement and confinement with latex

Fig. 10 shows that the layer of latex did not influence too much on the measured levels of stiffness of the mortars. The differences among all these curves together are the same if we make the comparisons only among curves with latex or curves without latex separately. This means that this variation is only the precision of the test. The behaviour is the same for the other formulations (Azeredo, 2005).

For the prismatic samples, the fact that the piston is not representative was also observed.

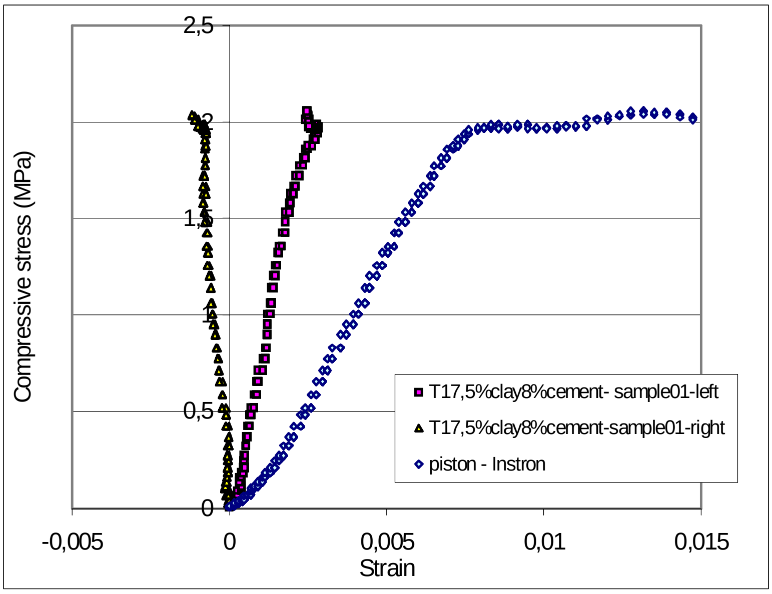

Fig. 8 Typical problem faced by measuring displacements by sensors of proximity

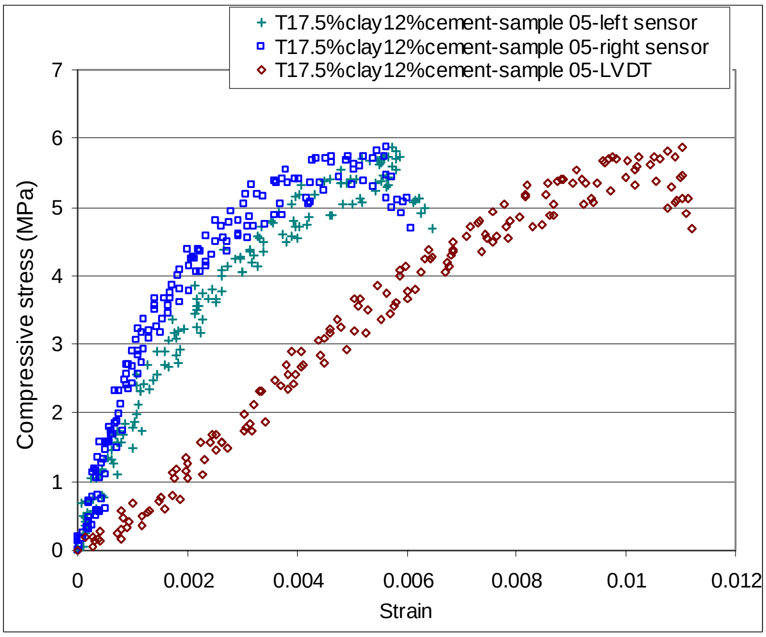

Fig. 9 Example of a good functioning of sensors of proximity

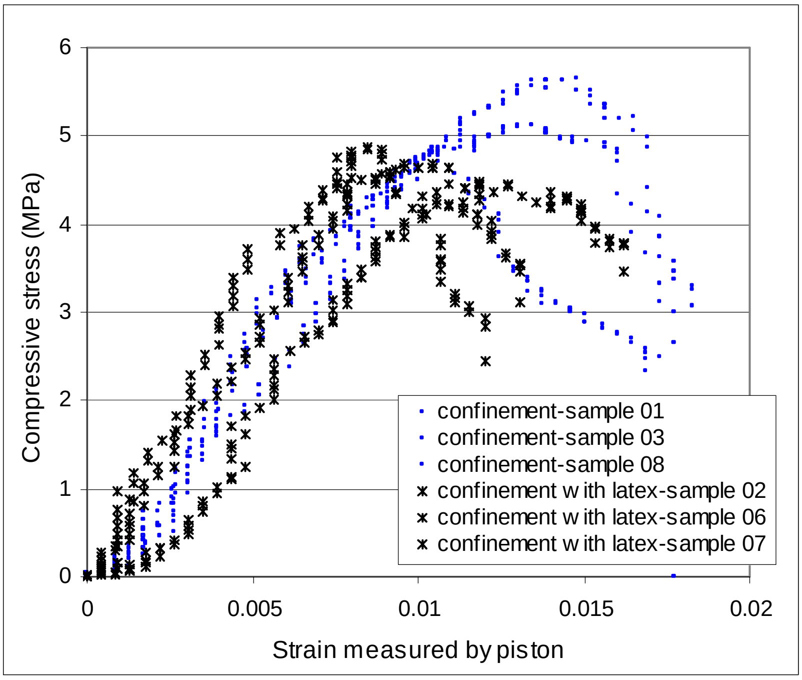

Fig. 10 Influence of latex on stress/strain curves – T17.5% clay + 12% cement (Azeredo 2002)

Conclusions about experimental device development

The selected procedure for the realization of the compressive tests was that shown in **Fig. 4**. We decided for the continuation of the use of sensors of proximity for the measurement of the homogeneous material strains. Efforts were made in the direction to decrease the geometrical defects of the samples caused for example by the moulding. Therefore, the prismatic geometry replaced the cylindrical one. To decrease the phenomenon of bending of the samples during the tests, we created a kneecap with the same dimensions as the cross section of the samples, because according to (Yurtdas, 2003), that improves considerably the centring of the loading, thus eliminating the effect from parasitic bending and the deformations of traction.

Concerning the ball which was used as kneecap, we also decided to lubricate it to improve its operation. The test was realized in displacement speed, controlled by the LVDT.

Compared to the kinematic conditions, we had decided to use only the system of confinement. On the other hand, with the good functioning of the kneecap and also the flatness of samples surfaces, the system of non-confinement was also used in the tests which were carried out *a posteriori* (Azeredo, 2005).

RESULTS FROM THE EXPERIMENTAL DEVICE ADOPTED - HARDENED EARTH MORTAR

Dry density variation for one formulation

The average values of the densities for the principal formulations of mortars and their respective standard deviations are presented in **Table 2**. The density varied from 1.51 to 1.86 g/cm3. Taking into account the weak standard deviations of the densities, we can regard them as identical for the same formulation. The error of measurement of our densities was approximately 0.05 g/cm3.

Strains

Sensors of proximity

We present certain curves of stress-strain obtained by sensors of proximity and the lvdt, so that we can make a comparison between the shapes of the curves. In general, for each formulation we manufactured 05 prismatic samples for tests of compression. For some samples, the left and right-hand curves of the sensors of proximity were coincidental. On the other hand, for other ones, each curve of the sensors of proximity took a different way, as it occurs in a bending test. If the values of stress were not close for all samples we could think that a bending phenomenon had happened during its crushing. But this is not true. So, we think that for the samples where the curves were not coincidental there was a separation of the targets under the sensors. This means that these measured values of displacement are parasitic.

We thus superimposed all the curves which went in the good direction, to check the coincidence among them and in this way have a more representative answer for the strain within the sample, without the influence of the plates of the press.

We thus present in **Fig. 11** the curves superimposed for the Tassin 17.5% clay + 12% cement mortar. One thus observes that in spite of the dispersion of stiffness and limit strains of the curves, this Fig. shows that it is possible to check what occurs within the sample. At least for the beginning of the curves, it is possible to obtain an average value of stiffness which is close to a real one, i.e. much larger than that determined by the curve given by the lvdt.

Also in **Fig. 11**, it is easier to estimate the stiffness than the limit strain. In fact, it is possible that the target does not move at the initial time of loading. On the other hand, with the increase of the loading, microscopic cracks appear in the centre of the samples, which can cause the movement of the targets.

In **Table 3**, we have some results obtained with the sensors of proximity. In this table, we also present the values of pseudo-stiffness and limit strains obtained by the lvdt. Often, only the values of stiffness could be measured, i.e. the two curves are coincidental at the initial time of loading, but separate before the rupture, either by separation of the targets or by an effect of non-homogeneous deformation. When the values of the stiffness obtained by the sensors of proximity (s.p.) are followed by "(@)", it means a good coincidence between the curves left and right-hand side of the sensors of proximity. In the other cases, the stiffness rather represents an average of stiffness between the two curves.

Table 2 Dry density, compressive strength, Pseudo-rigidity and medium limit strains from curves of LVDT for some tested formulations (samples 8×4×4 cm) – The standard deviations are shown beside the medium value for each parameter: media/standard deviation.

Mortars fomulations	ρ_d (g/cm^3)	σ_r (MPa)	E (MPa)	ϵ_{lim} (%)
T 17,5% clay	1.75/0.03	2.9/0.2	1.46/66	1,.6/0.17
T 17,5% clay + 8% cem	1.52/0.005	3.0/0.1	413/63	0.93/0.01
T 17,5% clay + 12% cem	1.51/0.005	5.8/0.3	766/86	1.00/0.08

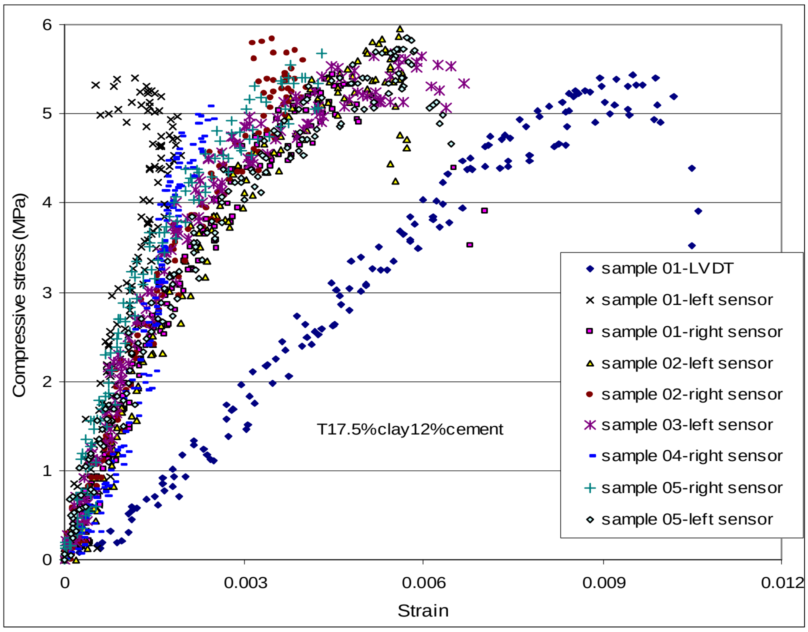

Fig. 11 – Curves obtained by proximity sensors - T17.5% clay + 12% cement mortar

CONCLUSIONS

We notice that about samples' geometry, the manufacturing of prismatic or cylindrical samples having height/diameter=2 functioned well, without considering the confinement usually present when cubic samples are used. About mortars' cure, non stabilized mortars samples can stay in the open air and stabilized ones in a humid room for 28 days. Concerning the use of kneecap, it was verified that the little kneecap system was more effective and provided more reliable results than the big one. About the platen restraint effects, we think that, if possible, the non-confinement system is the best one, despite its intrinsic difficulties in carrying out compressive tests. But the confinement system with latex functioned very well and neither changed the compressive strength value nor caused any experimental difficulty during the tests. Concerning the measuring of strains, for any platen restraint adopted, it is necessary to use an experimental device to obtain the homogeneous strain values, because it was shown here that measurements of stiffness obtained with the use of LVDT sensor was not exploitable because it is approximately 3 to 4 times weaker than those measured directly on sample by proximity sensors. The experimental device used in this research needs still some improvement, for measuring the real stiffness of earth mortars, perhaps a different way to fix the targets in the samples, avoiding their movements. Compared to the measurement of the limit strains by the sensors of proximity, we cannot conclude anything, because in this degree or time of the test, in general the targets had already undergone movement.

Table 3 Results of compressive strength, dry density, stiffness ($E_{c.p.}$) and pseudo- stiffness (E_{lvdt}) for mortars manufactured with Tassin earth containing 17%. Cement additions considered are 4%, 8%, and 12%. Tests realized over the prismatic samples having dimensions 8x4x4cm^3, except for Tassin 8% cement mortar, as indicated below. The pseudo-stiffness was determined by piston curve and the stiffness by sensors of proximity ones.

Mortars formulations Tassin	$E_{c.p.}$ (MPa)	ϵ_{lim} s.p. (%)	E_{lvdt} (MPa)	ϵ_{lim} Lvdt(%)
Tassin 17.5% clay + 4% cement	412	0.31	-	1.15
	-	1.25	-	1.46
Tassin 17.5% clay + 8% cement (12 × 8 × 6 cm)	1019	-	264	1.16
	1610	-	550	1.23
Tassin 17.5% clay + 8% cement	3191 (@)	0.30	420	0.93
	1857	0.38	473	0.91
	1576	0.31	451	0.93
	1836	0.54	410	0.95
	1374	0.44	310	0.94
Tassin 17.5% clay + 12% cement	2156 (@)	0.28	687	0.95
	1666 (@)	0.45	879	0.95
	1688 (@)	0.73	833	1.08
	1790	0.43	691	0.96
	2490 (@)	0.56	741	1.10

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