# MECHANICAL CHARACTERIZATION OF ADOBE BRICKS IN EXISTING CONSTRUCTIONS IN AVEIRO REGION, PORTUGAL

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**Summary**
In Portugal it is common to find earth constructions all over the country, being predominant in the centre and south. In the past, earth was massified as a construction material, used with different typologies and applications.
Adobe construction is confined mainly to the central part of the country and more viewed in the west coast (*gandaresa region*). Aveiro, an Atlantic sea line city is an excellent example of a place with several ancient adobe constructions, some with architectural and historical relevance like some *art-noveau* houses. Just a few ones have been preserved with the passing years. The majority are in the threshold of ruin and structurally weak needing an urgent solution for their furtherance as buildings. Preservation and rehabilitation of those constructions was simply forgotten, carrying to the actual situation.
In this context, becomes urgent, and absolutely necessary, to advance with rehabilitation and strengthening of these constructions.
A great difficulty for technicians working on the rehabilitation relies on the lack of knowledge on adobe's mechanical behaviour. In fact, in order to properly describe the structural behaviour of those constructions, there's a need to investigate the mechanical properties of adobe. Hence, this paper presents a study which intended to characterise the behaviour of adobe brick units. Specimens were prepared from selected representative Aveiro's constructions. The prepared specimens were tested in order to evaluate their mechanical behaviour in compression and tension.
Usually, adobe blocks were made from clay soils. A basic characterization was also performed by the adobes' granulometric analysis.

**Keywords**: Adobe, Mechanical behaviour, Compressive strength, Tensile strength, Young modulus

## 1. Introduction

The present situation of ruin and abandonment in which are found the majority of Portugal's adobe constructions, particularly in Aveiro's region, is conducing to the collapse of many. Persistently, the option for demolition has been the solution founded for these constructions, however, in the last years, sporadically, some property owners concerned with the urgency in maintenance and reparation of those constructions, proceed with the rehabilitation and strengthening.
Such change of attitude, associated with an increasing interest in rehabilitation revealed by public entities, that are carrying out projects and programs about adobe construction's rehabilitation, has taken a widened set of construction agents recommencing to be interested with adobe construction, specially in what concerns with rehabilitation and strengthening.
However, recurrently, many difficulties have been found, by these involved agents, in the search of information concerning the behaviour and mechanical properties' characterization of adobe.

Motivated by the recognition of those insufficiencies and the scarce existing technical information concerning adobe's mechanical properties, like for example: young modulus or compressive and tensile strength, the elaboration of this article aims to contribute, in an effective way, to reduce such lacunas. With the research performed, it was intended to create a data base of results that provide a support to the accomplishment of rehabilitation and strengthening projects of this kind of load bearing masonry, through the mechanical characterization of the Aveiro's region adobe blocks.
Thus, it's wished-for, the behaviour's study of this kind of material, in such a way that will allow the study of improvement solutions to the mechanical characteristics of adobe masonry.

## 2. Historical aspects

In Portugal, earth construction, as a structural element, is predominant in the south and central coast of the country. The north and central west are dominated by the stone and rubble stone masonry. The main constructive technique used in the south is the rammed earth called "taipa" in Portuguese.
Regarding to adobe construction, and despite its huge heterogeneities, confirmed by the numerous identified typologies, the majority of the constructions are confined to the central coast part.
In Aveiro's region is located the biggest implantation of adobe masonry construction. Initiated in the end of XIX century, it had its height in the first half of XX century, being gradually abandoned in the Sixties until its disappearance as constructive technique actually.
Presently, there are still several examples of historical patrimony, specially related with *Art Nouveau*, dominant artistic and architectural movement by the time, built in the region in adobe masonry. In the same way, although the patented state of degradation, there are countless examples of service and residential buildings, some with considerable size, which continue assuring the functions for which they had been projected, certifying the durability of adobe as a construction material. The employment of this material, in the region, was done, mostly, in the construction of houses and walls despite other known uses of adobe, like earth support and retention walls or, even, water wells.
The presence of adobe construction in Aveiro's region is also confirmed by the city council data about city existing constructions. According to their data, about 20-25% of city's existing constructions, currently, are made of adobe. The percentage increases to 35-40% referring to the Aveiro's region.
Usually, adobe blocks were made from wet mud which, after pressed and putted in forms, were left to dry in the sun. For the improvement of its mechanical performance it was quite frequent the inclusion of lime and straw. The usual dimensions varied with the use of the block, being 0.45×0.30×0.15m in the case of the houses and of 0.45×0.20×0.15m when used in the construction of walls.

## 3. Selection and execution of specimens

The huge variability of region's existing adobes makes it a material with a significant mechanical properties' heterogeneity. This difficulty has been taken into consideration in the selection of a set of representative samples of adobe's typologies used in the region. Therefore, selected walls and houses' specimens, from three houses and five

walls, had been collected in distinct region's locations, in order, to characterize as ample as possible the existing variety of adobes in the region.
To make easier the identification and analysis, the obtained specimens were numbered and classified, according to its provenience, distinguishing, respectively, specimens from houses and walls with the notation: C_i and M_i, where i represents the number of the construction which it belongs, in addition it is used an index j, when it's mentioned a specific specimen from one of the constructions.
Specimens were collected mostly in Aveiro city, beside that, samples from a house (C_03) and a wall (M_05) were collected in the northern region of Aveiro, respectively, in the rural communities of Bestida and Murtosa. The collected samples were composed by entire adobe blocks with the respective mortar of bed joint and plaster. With an exception for the blocks from the M_03 wall, it was possible to extract, from all the other adobes, cylindrical cores with a diameter of, approximately, 90mm. Those cores were cut, with a height of approximately two times the adobe core diameter. Cores' top faces were regularised to be perfectly perpendicular to its axis and normalized its dimensions, with the purpose of being tested in similar conditions of orthogonality and size and in accordance with the norms of the compression tests [9].
The appearance of the obtained specimens was different, what will be reflected in the, subsequent achievement of different results of mechanical strength, as well as, granulometric composition.

## 4. Granulometric characterization

Adobe blocks were, essentially, made with arenaceous soils with an argillaceous nature. A basic characterization of its composition was done by the granulometric analysis of the specimens' aggregates. From the analysis of the granulometric curves obtained, for four specimens (C_01, M_01, M_02 and M_0), two relevant facts outcome:

- Only the aggregates that compose adobes, from C_01 house had been classified as medium sand. All the other adobes, the M_01, M_02 and M_03 walls, had been classified as being coarse sand.

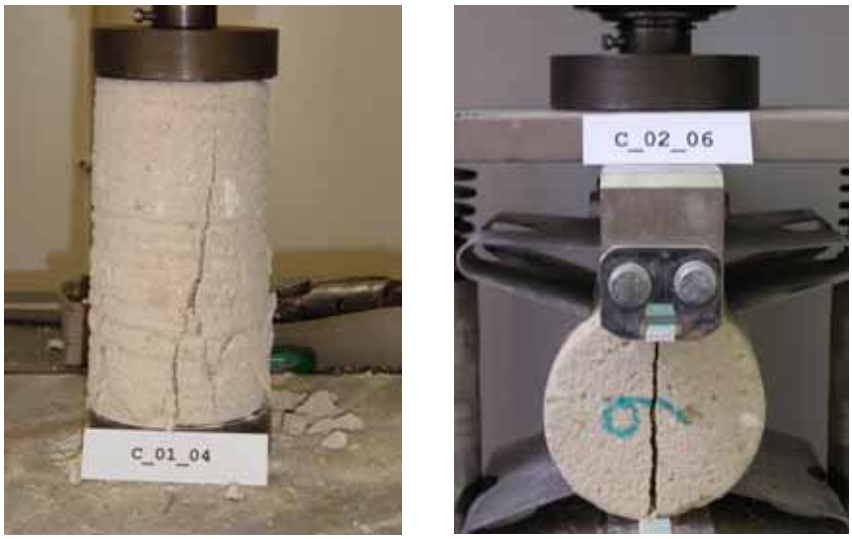
- In the case of the M_03 wall, the major fraction of aggregates with a dimension larger than 2.5mm, made not viable the extraction of regular cores due to the cores' damage produced during the extraction process.

## 5. Mechanical tests

Due to adobe standard mechanical tests' inexistence, it were adopted the RILEM technical recommendations [9], used for concrete specimens' tests, to determine compressive and tensile strength of the adobe specimens.
The compressive strength was determined because it is the most common performance measure used by the engineers in the design and assessment of buildings and other structures. It's calculated from the failure load divided by the cross-sectional area resisting the load and reported in units [$N/mm^2$] as described in RILEM CPC4[9].
The diametral compression test was used to estimate the tensile strength of the adobe. A compressive load was applied across the diameter of the specimen creating a nearly uniform state of tension across a vertical plane. Tensile strength of the specimen was measured by increasing the compressive load until the specimen fails in tension. The tensile strength, as described in RILEM CPC6 [9], is given by $\sigma = 2F/(\pi DH)$ [$N/mm^2$],

where: F is the load applied [N]; D is the diameter of the specimen [mm]; and, H is the height of the specimen [mm].

A total of 40 cylindrical specimens were submitted to destructive tests of mechanical strength, 18 proceeding from houses and 22 from walls. The specimens were divided in two groups, one to perform compression tests, and the other for diametral compression tests, as illustrated in Fig.1.



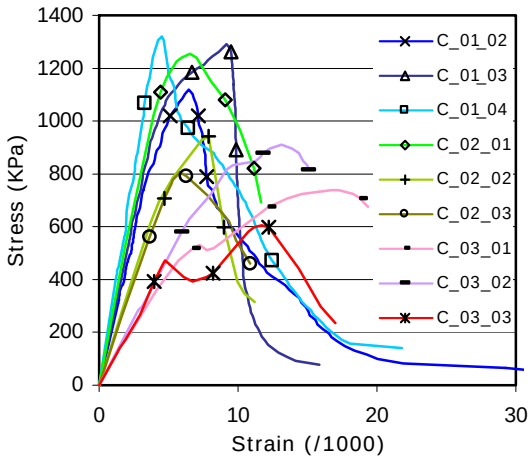

a) simple compression b) diametral compression

Fig.1 – Specimen's mechanical tests

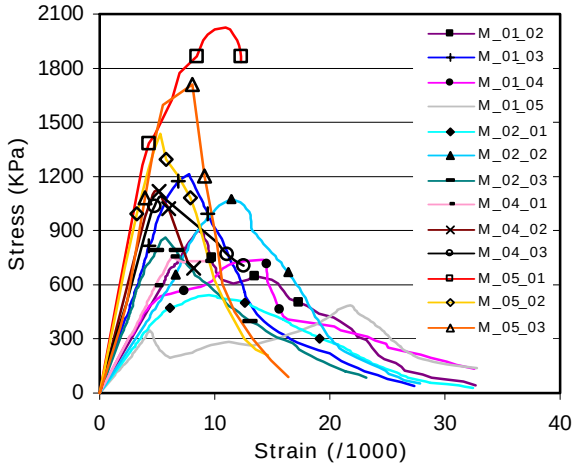
For the C_01 house, additionally, a simple compressive strength test, of its bed joint mortar, was developed.
In this case, the test was different from the previous, given the reduced dimensions of the plaster mortar, two square steel plates had been used, graduated with 4 centimetres, placed one of each side of the mortar specimen in which were applied the force transmitted from the plates of the compression machine.

## 6. Analysis and discussion of the results

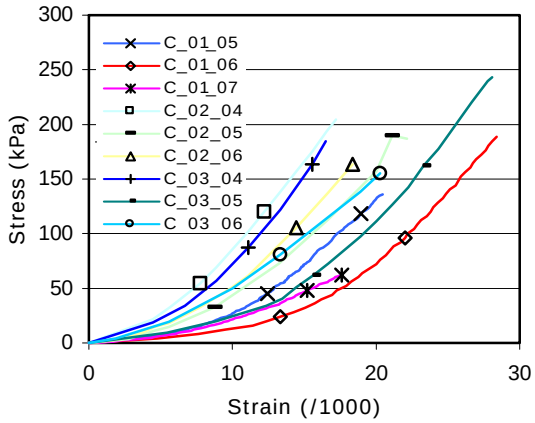
The mechanical tests' accomplishment, of simple and diametral compression, allowed the achievement of, respectively, adobe's compressive and tensile strength. It was also possible to obtain an estimation of the specimens' young modulus and the corresponding strain at peak strength. Such was possible by the behaviour curves, stress-strain, of each tested specimen. In Fig.2 are presented the curves (simple and diametral compression), setting apart house and wall specimens. In Table I are summarized, for each test, the obtained results.



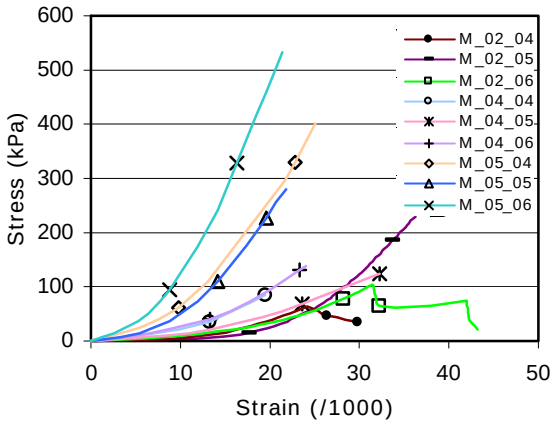

a) simple compression: house specimens




b) simple compression: wall specimens




c) diametral compression: house specimens




d) diametral compression: wall specimens

Fig.2 – Specimens' behaviour curves: stress vs. strain

Table I – Summary table of the test results

| Specimen | | | Mechanical properties | | | |
|---|---|---|---|---|---|---|
| | | | Young Modulus [MPa] | Compressive strength [kPa] | Strain at peak [1/1000] | Tensile strength [kPa] |
| Houses | House 1 | C_01_02 | 230.0 | 1118.0 | 6.5 | -- |
| | | C_01_03 | 250.0 | 1291.5 | 9.2 | -- |
| | | C_01_04 | 340.0 | 1320.4 | 4.5 | -- |
| | | C_01_05 | -- | -- | -- | 136.1 |
| | | C_01_06 | -- | -- | -- | 188.5 |
| | | C_01_07 | -- | -- | -- | 62.2 |
| | | Average | 273.3 | 1243.3 | 6.7 | 128.9 |
| | House 2 | C_02_01 | 280.0 | 1253.6 | 6.5 | -- |
| | | C_02_02 | 170.0 | 943.1 | 7.9 | -- |
| | | C_02_03 | 160.0 | 806.9 | 5.8 | -- |
| | | C_02_04 | -- | -- | -- | 204.3 |
| | | C_02_05 | -- | -- | -- | 189.6 |
| | | C_02_06 | -- | -- | -- | 163.6 |
| | | Average | 203.3 | 1001.2 | 6.8 | 185.8 |
| | House 3 | C_03_01 | 95.0 | 738.8 | 16.7 | -- |
| | | C_03_02 | 100.0 | 911.7 | 13.2 | -- |
| | | C_03_03 | 95.0 | 605.2 | 11.7 | -- |
| | | C_03_04 | -- | -- | -- | 184.3 |
| | | C_03_05 | -- | -- | -- | 243.3 |
| | | C_03_06 | -- | -- | -- | 155.1 |
| | | Average | 96.7 | 751.9 | 13.9 | 194.2 |
| Walls | Wall 1 | M_01_02 | 110.0 | 899.9 | 8.6 | -- |
| | | M_01_03 | 185.0 | 1213.6 | 7.8 | -- |
| | | M_01_04 | 120.0 | 737.4 | -- | -- |
| | | M_01_05 | -- | -- | -- | -- |
| | | Average | 138.3 | 950.3 | 8.2 | -- |
| | Wall 2 | M_02_01 | 85.0 | 542.8 | 9.5 | -- |
| | | M_02_02 | 97.0 | 1075.0 | 11.5 | -- |
| | | M_02_03 | 170.0 | 860.8 | 5.7 | -- |
| | | M_02_04 | -- | -- | -- | 63.2 |
| | | M_02_05 | -- | -- | -- | 229.6 |
| | | M_02_06 | -- | -- | -- | 104.4 |
| | | Average | 117.3 | 826.2 | 8.9 | 132.4 |
| | Wall 4 | M_04_01 | 120.0 | 754.5 | 6.3 | -- |
| | | M_04_02 | 250.0 | 1123.9 | 5.0 | -- |
| | | M_04_03 | 230.0 | 1092.5 | 5.4 | -- |
| | | M_04_04 | -- | -- | -- | 85.4 |
| | | M_04_05 | -- | -- | -- | 124.0 |
| | | M_04_06 | -- | -- | -- | 138.1 |
| | | Average | 200.0 | 990.3 | 5.6 | 115.8 |
| | Wall 5 | M_05_01 | 340.0 | 2024.8 | 10.9 | -- |
| | | M_05_02 | 320.0 | 1436.6 | 5.3 | -- |
| | | M_05_03 | 190.0 | 1708.9 | 8.2 | -- |
| | | M_05_04 | -- | -- | -- | 401.3 |
| | | M_05_05 | -- | -- | -- | 279.6 |
| | | M_05_06 | -- | -- | -- | 532.8 |
| | | Average | 283.3 | 1723.4 | 8.1 | 404.6 |

The result analyses show that M_05 wall had the highest results of compressive and tensile strength, 1.7MPa and 0.4MPa, respectively. In opposition, the M_01 wall presented the worst performance in terms of compressive strength, 0.8MPa, being the test specimens of the M_04 wall which presented the lowest tensile strength, 0.1MPa.

For the specimen M_01_05, the obtained curve was inconclusive, so this result was not considered.

The C_01 plaster's mortar compressive strength was 2.8MPa. This result is very significant, because its strength is higher than the obtained for adobe blocks. A possible explanation for this fact is the percentage of lime traditionally used on mortar's manufacture, normally, higher than the used on adobe blocks, what provides a higher strength for the mortar.

Finally, in Fig.3 are plotted, for each test series (house or wall), the average strength obtained from the compression and diametral compression tests.

In an attempt to find a correlation between the two strengths the obtained results for Aveiro's adobes were compared with the results presented in the study of Vargas *et al.* [1].

In the Vargas *et al.* work, soils from six zones of Peru: Cajamarca; Cuzco; Huancayo B.; Huaraz, Pisco and PUC, where adobe construction is traditional, were selected. These soil samples were collected in order to correlate their mechanical characteristics with the strength of adobe masonry made with these soils. A part of the mechanical

characterization done, in this study, was the evaluation of compressive and tensile strength of the adobe, being the obtained results used, into the present work, to enlarge the adobe's strengths assemblage.
From the graphic in Fig.3, it can be observed that, confronting the results from Aveiro and Vargas *et al.* [1], the adobe studied from Aveiro has higher strength (compressive and tensile), and, it's possible, as well, to perceive, sticking together all the points of the graphic, a tendency for a correlation between the compressive and tensile strength.

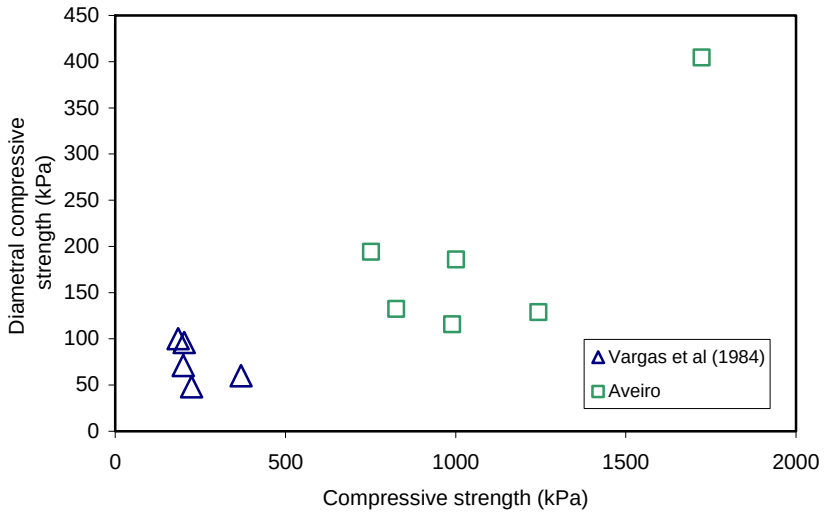



Fig.3 - Compressive strength vs. diametral compressive strength

## 7. Conclusions

The main objective of this work was to characterize adobe's mechanical behaviour and strength (in compression and tension).The obtained results in simple compression tests show a significant compressive strength (0.5-2.0MPa), being for the tensile strength, also expressive the achieved results of approximately 20% of the respective compressive strength.
A differentiate analysis of the results, comparing mechanical strength of test specimens proceeding from houses and walls, reveals a preponderance for better results, in terms of stiffness (modulus of elasticity) and strength (in compression and tension), in the test specimens proceeding from houses.
From the point of view of the granulometric distribution, aggregates' constitution, show a clear tendency for better results of compressive and tensile strength for specimens with bigger fractions of smaller particles.
As a result of this study, there are, some, indirect, achieved practical indications about adobe strength that can be used in rehabilitation and strengthening projects, like the percentage of lime used on mortar's manufacture, as well as, the use of large fractions of small dimensions aggregates.
This work will be, in the future, complemented with absorption and drying tests of the adobe specimens.

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**References**

- [1] VARGAS, J; BARIOLA, J.; BLONET, M; MEHTA, K. (1984): "Seismic strength of adobe masonry - Tutorials on Earthquake-Resistant Housing Construction Practices", Adobe tutorials, Earthquake Engineering Research Institute, U.S. Agency for International Development (AID), Research Project DI-84-01.
- [2] ARANGO GONZÁLEZ, J.R. (1999): "Uniaxial deformation-stress behaviour of the rammed-earth of the Alcazaba Cadima", Materials and Structures, University of Granada, Spain.
- [3] VEIGA OLIVEIRA, E; GALHANO, F. (1992): "Arquitectura Tradicional Portuguesa", Portugal de Perto, Publicações D. Quixote, Lisbon.
- [4] Seminário (1992): "Arquitecturas de Terra", Museu Monográfico de Conímbriga, Ed. CCRCentro, Coimbra.
- [5] DETHIER, J. (2002): "Arquitecturas de Terra ou o Futuro de uma Tradição Milenar", Fundação Calouste Gulbenkian, Dinalivro, Lisbon.
- [6] TOLLES, E.L.; KIMBRO, E.E.; WEBSTER, F.A.; GINELL, W.S. (2000): "Seismic Stabilization of Historic Adobe Structures – Final Report of the Getty Seismic Adobe Project", The Getty Conservation Institute, Los Angeles, CA.
- [7] PUCP/CIID, "Nuevas Casas Resistentes De Adobe", Pontificia Universidad Católica del Perú, Centro Internacional de Investigación para el Desarrollo (CIID), Lima, Perú.
- [8] MINKE, G. (2005) "Manual de Construcción para viviendas antisísmicas de tierra", Forschungslabor für Experimentelles Bauen, University of Kassel, Germany.
- [9] RILEM (1994) "RILEM Technical Recommendations for the Testing and Use of Construction Materials", E & FN Spon, London, England.
- [10] EERI (2003). "World Housing Encyclopedia", Earthquake Engineering Research Institute, Oakland, CA.