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The Portuguese masonry's mechanical characterization

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ABSTRACT:
The aim of this study is the characterization of the mechanical properties of typical masonry components in Portugal and the definition of mortar compositions, with direct implication to the National Annex of EC6. For masonry units the following were evaluated: the dimensions; water absorption and compressive strength. To assess mortar parameters such as, consistence, air content, compressive and flexural tensile strength, fracture energy and shrinkage, an analysis with various types of traditional and ready-to-use mortars was also performed. For several traditional mortars with different compositions and various strength classes, by varying the type of binder (cement, hydrated lime and hydraulic lime) and the type of sand (natural or artificial), it was possible to draw some conclusions about the parameters mentioned, such as: for the same strength class, the study compositions presented higher values of binder than the EC6 compositions and the shrinkage of cement mortars develops quicker than that of mixed mortars; for the same kind of sands there is a straight relationship between the maximum load applied and fracture energy. An experimental characterization of mechanical properties of masonry specimens was also made including flexural strength, compressive strength and Young's modulus.

Keywords: *Mortar, brick, masonry, shrinkage, fracture energy*

1 INTRODUCTION

The building envelope in Portugal is usually made of masonry walls, which enclose a building or may be infill panels in frame structures. Walls are one of the most relevant subsystems in buildings, separating the indoor from the outdoor environment, and have a decisive role in building performance. Despite such major relevance, masonry walls are generally insufficiently detailed, due to their building characteristics and the lack of tradition in research and teaching. The performance of masonry walls however is poor and accounts for around 25% of total building damage. Masonry walls are a subsystem that incorporate elements of very high cost, such as: finishings, installations and windows. The walls also interact with other subsystems, and may control the building sequence of different tasks. The cost of masonry in Portugal is about 8.5 - 10.5 % of total building cost, making the total annual value of masonry works about 1275 M Euros. Therefore, masonry walls have a major economic importance and contribute to building performance. The fact that they are of ten sub-standard due to poor quality of materials, workmanship, design and detailing is regrettable.

The aim of this study therefore is the mechanical characterization of typical masonry components and specimens and the definition of characteristics that provide masonry with a better ability to accommodate deformations.

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2 CLAY MASONRY UNITS

The clay masonry units usually adopted in Portugal have horizontal perforations. Table 1 indicates the main units manufactured, and includes: dimensions, weight, percentage of perforations and compressive strength. In this programme the main characteristics of the clay masonry units were evaluated by laboratory tests: dimensions, water absorption and compressive strength.

Table 1. Main properties of the Portuguese clay masonry units.

	Clay masonry units	**Dimensions** (mm)			**Weight** (Kg)	**Percentage perforation**	**Compressive strength** (N/mm^2)
		Length	**Height**	**Width**			
	30x20x22	300	200	220	7.0 - 11.0	55 - 70	1.9 - 3.9
	30x20x15	300	200	150	5.0 - 7.0	50 - 65	2.5 - 4.9
	30x20x11	300	200	110	4.0 - 6.0	50 - 65	2.8 - 5.2
	30x20x7	300	200	70	3.0 - 5.0	40 - 60	3.7 - 7.0

2.1 Dimensions

The dimensions of the clay masonry units were determined by NP EN 772-16 [1]. The results are presented in Table 2. It appears that some of the results did not meet the requirements of the National Annex of EC6. The shells thickness is less than 10 mm and in this unit type and size (30x20x11 cm), the maximum percentage of perforations was exceeded.

Table 2. Mean dimensions of the clay masonry units.

Units	**Dimensions** (mm)			**Thickness** (mm)		**Area of voids** (mm^2)		**Percentage perforation**
	Length	**Height**	**Width**	**Shells**	**Webs**	**Single**	**Total**	
30x20x11	296.5	195.0	110.0	8.5	7.5	1652	13216	61.6%
30x20x15	295.0	188.5	147.0	9.0	8.0	1364	16370	59.2%

2.2 Water absorption

The water absorption of the clay masonry units were determined in accordance with Annex C of EN 771-1 [2]. The mean water absorption obtained for this sample of units was 14.8% for the units of size 30x20x11 cm and 15.4% for the units of size 30x20x15 cm. The samples tested showed high levels of water absorption when compared with tabulated reference values, which for brick manufactured in Portugal, should be between 9% and 13%.

2.3 Compressive strength

The compressive strength of the clay masonry units were determined by NP EN 772-1 [3].The results are presented in Table 3, where *mc* is the adjustment factor depending on the moisture, δ the shape factor and *s* the standard deviation. The mean compressive strength, obtained for this sample, showed low values for the tested mechanical characteristics when compared with tabulated values and reference values provided by manufacturers. For units of size 30x20x11 cm the values should be between the 2.8 and 5.2 N/mm^2 and the for units of size 30x20x15 cm, between 2.5 and 4.9 N/mm^2.

Table 3. Mean compressive strength of the clay masonry units

Units	f (N/mm^2)	mc	δ	f_b = mc.δ.f (N/mm^2)	s (N/mm^2)
30x20x11	2.1	1	1.349	2.9	0.361
30x20x15	2.5	1	1.275	3.1	0.268

3 MORTARS

Another aim of this study was the mechanical characterization of the mortar compositions usually adopted in Portugal (where the usage of lime is limited), taking into account the European testing standards and to ascertain the difference between the properties found in the laboratory and in situ. These tests will be directly incorporated in the National Annex of EC 6 [4]. The mortars mechanical characteristics were evaluated by laboratory tests. For fresh mortars the consistence and air content were evaluated. For hardened mortars the compressive and flexural tensile strength, the shrinkage and fracture energy, were found.

3.1 Composition proposal

For possible further inclusion in the National Annex of EC 6 [4], different mortar compositions were studied, using three types of binder (cement, air-lime, hydraulic lime) and two types of sands (artificial and natural) located within the limits imposed by BS1200 [5], with the aim of achieving the following strength classes: M2, M5 and M10. The mortars were made to a standard consistence (160 mm), using whatever water was needed to do so. Table 4 presents the study proposal.

Table 4. Study Composition Proposal (in volume parts).

Class	Composition				Compressive strength 28 days [MPa]
	Cement	Air-lime	Hydraulic lime	Sand	
M10	1			3	10.0
M5	1			4	5.0
M5	1	1 ½		5	5.0
M5	1		1	5	5.0
M2	1			6	2.0
M2	1	1 ½		7	2.0
M2	1		1	7	2.0

3.2 Mechanical characteristic evaluation of mortar

The mechanical characteristics of the mortars were evaluated by laboratory tests. Table 5 presents the different mortar compositions studied. For each class of strength the behaviour of two types of sands: one artificial, A, and other natural, N was evalutated. The research, included, two ready-to-use mortars: one dry-mixed mortar, CI, and an other ready-mixed mortar, BE. As the tests were performed at 7, 14 and 28 days, it wasn’t possible to conclude if the lime mortars were fully carbonated.

3.3 Compressive and flexural strength

The compressive and flexural strength were determined by EN1015-11: 1999 [6]. Three samples were included for compressive strength tests and six for flexural strength testing. The results are presented in Table 6, where *s*, is the standard deviation, and ft_{med}, fc_{med}, are, respectively, the mean flexural and compressive strengths.

Table 5. Study mortars composition.

Mortar	Composition	W/C	Cement	Hydraulic lime	Air-lime	Sand		Water
			(kg)	(kg)	(kg)	Type	(kg)	(dm^3)
M2_C_A	1:6	1.26	1.2			A	8.96	1.51
M2_C_N	1:6	1.69	1.2			N	9.24	2.03
M5_C_A	1:4	1.15	1.2			A	5.98	1.38
M5_C_N	1:4	1.13	1.2			N	6.16	1.36
M10_C_A	1:3	0.86	1.2			A	4.48	1.03
M10_C_N	1:3	0.83	1.2			N	4.62	1.00
M2_C+HL_A	1:1:7	2.10	1.2	0.6		A	10.43	2.52
M2_C+HL_N	1:1:7	1.71	1.2	0.6		N	10.78	2.05
M5_C+HL_A	1:1:5	1.44	1.2	0.6		A	7.45	1.73
M5_C+HL_N	1:1:5	1.28	1.2	0.6		N	7.70	1.54
M2_C+HT_A	1:1:7	2.00	1.2		0.6	A	10.43	2.40
M2_C+HT_N	1:1:7	1.87	1.2		0.6	N	10.78	2.25
M5_C+HT_A	1:1:5	1.54	1.2		0.6	A	7.45	1.85
M5_C+HT_N	1:1:5	1.22	1.2		0.6	N	7.70	1.46
CI	Dry-Mixed Mortar (≥ 5MPa)							
BE	Ready-Mixed Mortar (≥ 10MPa)							

Table 6. Compressive and flexural strength.

Mortar	Required class	**Flexural** (N/mm^2)		**Compression** (N/mm^2)	
		ft_{med}	s	fc_{med}	s
M2_C_A	M2	1.20	0.07	2.70	0.16
M2_C_N	M2	1.20	0.11	2.80	0.24
M5_C_A	M5	1.90	0.13	5.65	0.46
M5_C_N	M5	2.70	0.23	7.00	0.45
M10_C_A	M10	2.45	0.04	10.80	0.58
M10_C_N	M10	3.10	0.38	11.30	0.78
M2_C+HL_A	M2	1.25	0.09	3.30	0.27
M2_C+HL_N	M2	1.20	0.09	3.30	0.22
M5_C+HL_A	M5	1.60	0.04	5.25	0.22

M5_C+HL_N	M5	1.65	0.07	5.35	0.15
M2_C+HT_A	M2	1.15	0.03	2.55	0.09
M2_C+HT_N	M2	0.90	0.19	2.65	0.19
M5_C+HT_A	M5	1.90	0.02	4.70	0.19
M5_C+HT_N	M5	1.40	0.11	4.70	0.10
CI	M5	1.70	0.33	4.35	1.46
BE	M10	3.20	0.13	9.90	0.13

It was confirmed that mortars made with natural sands and within the same class of strength and with the same binder content have higher strength values than for artificial sand. This fact is mainly concerned with the amount of water used in the composition of the mortar made with artificial sand. To get the same results in the flow table in all mortars, we need to use more water in the mortar made with artificial sand than in the mortars made with natural sand. The water/cement ratio is an important parameter in obtaining high mechanical strength. As this ratio is higher in artificial sand mortars, the results obtained for the compressive strength were lower. The cement mortars for classes M2, M5 and M10 have reasonable mechanical strength, and natural sands give higher strenght when compared to artificial sand. We can see that the mortar made of cement and hydraulic lime obtained the desired results, and once again, the natural sand had higher values. With the exception of class M5, the cement and air-lime mortar also showed the expected results for the class of strength for which the compositions were formulated. With these mortars the difference in the compressive values was not so obvious, but the natural sand had better results again. This is due to the hardening of these mortars by carbonation, while in cement mortars and cement mortars with hydrated lime the hardening process is mostly by hydration, and faster than the lime types.

3.4 Air content

The air content of mortars was determined by EN1015-7: 1999 [7]. The results are presented in Table 7, where *s* is the standard deviation, and *Ta*, the air content of mortars.

Table 7. Air content.

Mortar	**Required class**	**Air content** (%)	
		Ta	**s**
M2_C_A	M2	10.9	0.14
M2_C_N	M2	10.0	0.28
M5_C_A	M5	8.7	0.28
M5_C_N	M5	8.1	0.14
M10_C_A	M10	6.4	0.28
M10_C_N	M10	5.9	0.21
M2_C+HL_A	M2	7.1	0.14
M2_C+HL_N	M2	10.5	0.00
M5_C+HL_A	M5	8.2	0.00
M5_C+HL_N	M5	9.3	0.14
M2_C+HT_A	M2	7.8	0.00
M2_C+HT_N	M2	8.5	0.14
M5_C+HT_A	M5	6.6	0.28
M5_C+HT_N	M5	8.6	0.00
CI	M5	14.6	0.00
BE	M10	25.0	0.14

The cement mortars made with artificial sand showed higher air content values for the three classes of strength analyzed. We also observed that the air content decreased when the percentage of binder increased. The same relation was observed with the increasing of strength class.

It was also observed, that the mortars of cement and hydraulic lime with natural sands, presented higher values in air content for both classes of strength.For the cement and hydraulic lime mortars it was found that the natural sands showed a higher content of air for both types of strength.

In the ready-to-use mortars it was found that ready-mixed mortar, BE, had a value of air content significantly higher compared to mortars produced in the laboratory. The explanation for this may be the fact that in the laboratory an air entraining admixture was added to increase the workability of the mortar. The dry-mixed mortar, CI, also had a value of air content higher than the average values for the mortars produced in the laboratory but roughly half of that of the ready-mixed mortar, BE.

3.5 Shrinkage

The shrinkage of mortars was determined by the specification LNEC E398 [8]. The results are presented in Figures 1 to 4. Although the tests were carried out under controlled temperature and humidity it was noted there were long term variations in the test facilities.

For all mortars, it was observed that the higher the mortar's strength class (due to increased binder quantities), the higher was the value of shrinkage. When comparing all mortars within the same class, it is possible to observe that the „mixed" mortars had higher values of shrinkage when compared with cement mortars. Those that had higher values of shrinkage were the cement and hydrated lime mortar, the cement and hydraulic lime, and finally the cement mortars. Shrinkage is caused mainly by loss of water over time. Therefore mortars with high percentages of water lead to higher values of shrinkage. This may explain why cement and hydrated lime mortars had a higher shrinkage. They required a greater amount of water in order to obtain the same workability, as shown in Table 5. However, besides these mortars requiring more water, less water is consumed in carbonation, unlike what happens to the water in the hydration of hydraulic binders. The cement mortars, in turn, are the mortars that require less water, leading to a smaller value of shrinkage.

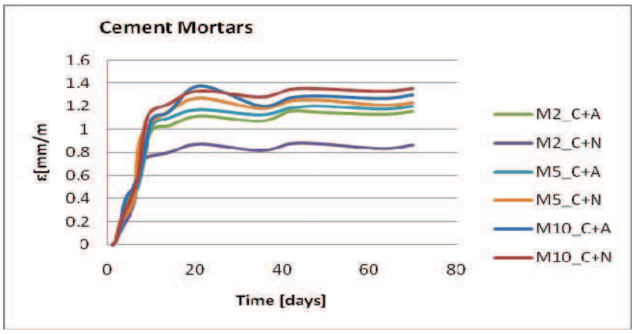


Figure 1. The shrinkage evolution of the cement mortars.

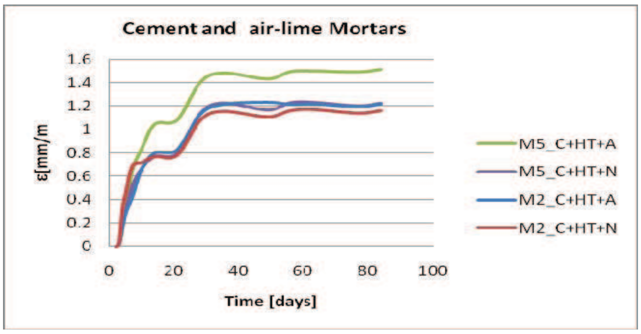


Figure 2. The shrinkage evolution of the cement and air-lime mortars.

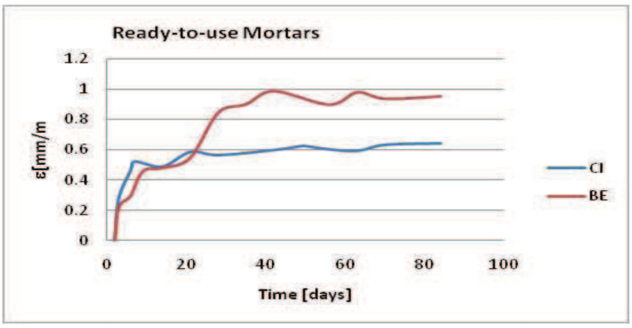


Figure 3. The shrinkage evolution of the ready-to-use mortars.

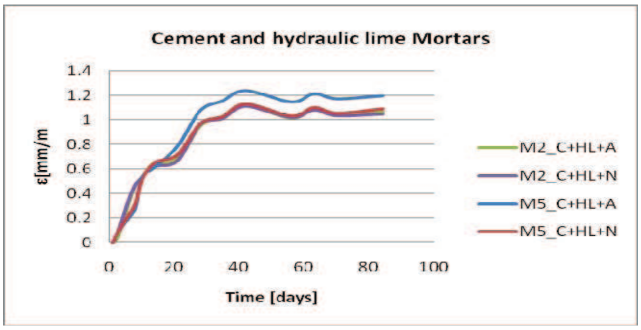


Figure 4. The shrinkage evolution of the cement and hydraulic lime mortars.

The ready-to-use mortars have a value of shrinkage significantly lower than the traditional mortars produced in the laboratory. This is mainly due to there being less water in their composition, that would lead to a decrease in the amount of binder, contributing to lower values of shrinkage.

3.6 Fracture energy

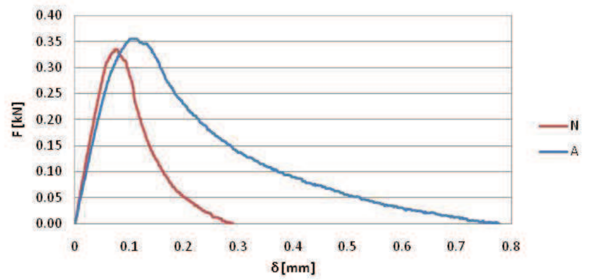
The fracture energy of mortar was determined using the specification in RILEM_TC50-FMC: 1985 [9]. The results are presented in Table 8, where, δ_0, is the final deformation at failure; F_{max}, is the maximum force applied; *RF*, the flexural strength at 28 days; and *RC*, is the compressive strength at 28 days. In Table 8 we compare the values of fracture energy, G_f, with ratio of flexural/compressive strength, which is the ductility [10].

From the analysis of the results it is established that the artificial sand mortars, for all classes and all types of binders, have greater values of fracture energy, as show in figures 5 and 6.

For mortars of the same strength class, the maximum load is similar. When the maximum load is reached, for the mortars with artificial sand there is always a displacement slightly in excess to that for natural sand mortars. During application of the load it is observed that the artificial sand mortars have a better absorption capacity for load, reaching a displacement at failure much higher than with the natural sand mortars. The displacement between the mortars made using the two sands followed a similar pattern until failure when the displacement in the artificial sand mortars was sometimes double that obtained in natural sand mortars. This fact is connected with the adhesion between the artificial sand and the cement paste, which in this case is much higher when compared with what happens in the natural sands, which by their sphericity, and the high length/width grain of sand ratio, leads to greater internal friction. This friction leads to higher values for displacement until it reaches the maximum load when compared to natural sand mortars. For ready-to-use mortars it was found that the dry-mixed mortar, CI, class M5 obtained values of fracture energy very similar to ready-mixed mortar, BE, class M10. Once again, the final displacement occurred was the factor that contributes to higher values of fracture energy.

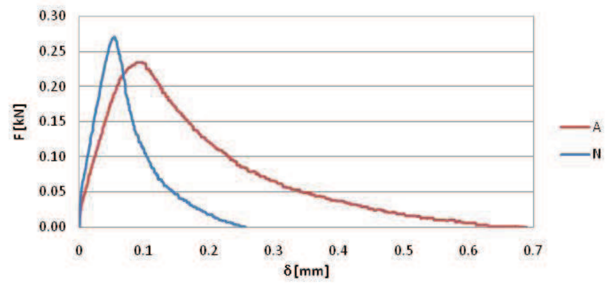
Table 8. Fracture energy.

Mortar	**δ_0** (mm)	**F_{max}** (kN)	**G_f** (N/m)	**RF** (N/mm^2)	**RC** (N/mm^2)	**RF/RC**
M2_C_A	0.44	0.23	19.24	1.232	2.742	0.449
M2_C_N	0.28	0.30	9.76	1.221	2.831	0.431
M5_C_A	0.70	0.37	28.81	1.900	5.660	0.336
M5_C_N	0.28	0.32	11.44	2.720	7.090	0.384
M10_C_A	0.87	0.77	48.72	2.480	10.813	0.229
M10_C_N	0.59	0.82	32.23	3.140	11.317	0.277
M2_C+HL_A	0.49	0.23	16.63	1.270	3.323	0.382
M2_C+HL_N	0.27	0.26	9.48	1.211	3.322	0.365
M5_C+HL_A	0.73	0.41	29.96	1.614	5.250	0.307
M5_C+HL_N	0.48	0.46	20.49	1.692	5.381	0.314
M2_C+HT_A	0.49	0.16	15.35	1.165	2.566	0.454
M2_C+HT_N	0.18	0.15	6.53	0.895	2.658	0.337
M5_C+HT_A	0.55	0.29	20.97	1.942	4.714	0.412
M5_C+HT_N	0.47	0.34	18.02	1.439	4.730	0.304
CI	0.44	0.39	16.02	3.215	9.926	0.324
BE	0.40	0.60	17.41	1.735	4.346	0.399



A, Artificial Sand	W_0=0,090	F_{max}=0,374	δ_0=0,702	δ_{Fmax}=0,104	G_f=28,81
N, Natural Sand	W_0=0,035	F_{max}=0,321	δ_0=0,277	δ_{Fmax} =0,076	G_f=11,44

Figure 5. Cement mortars. Resistance class M5: M5_C_A; M5_C_N. Average values of fracture energy.



A, Artificial Sand	W_0=0,044	F_{max}=0,229	δ_0=0,440	δ_{Fmax}=0,086	G_f=19,24
N, Natural Sand	W_0=0,024	F_{max}=0,295	δ_0=0,278	δ_{Fmax} =0,058	G_f=9,76

Figure 6. Cement mortars. Resistance class M2: M2_C_A; M2_C_N. Average values of fracture energy.

As shown in graphs in figures 7 and 8, by using a linear regression it can be seen, in a very simplistic way, that a relationship between the maximum force applied and the fracture energy exists when mortars are produced with the same type of sand. As show in the graphs of figures 9 and 10, the same correlation also can be found between the ratio of flexural/compressive strength (ductility) and the fracture energy calculated.

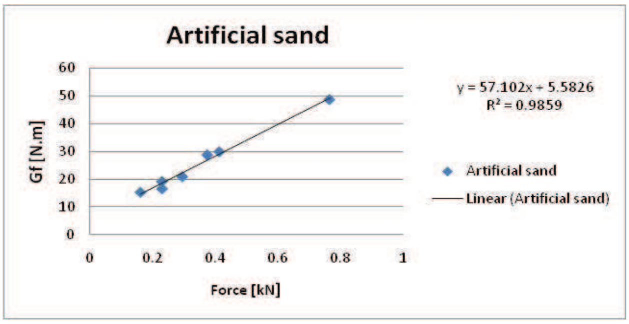


Figure 7. Artificial sand. Relationship between the maximum force applied and the fracture energy.

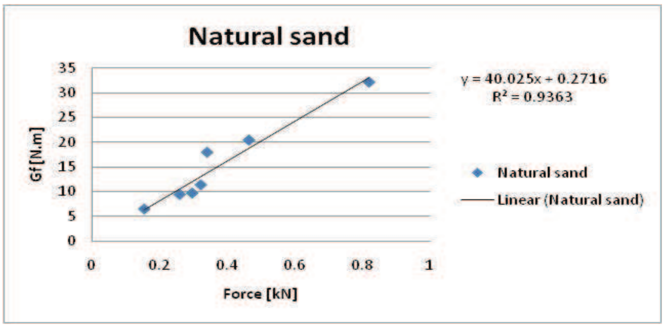


Figure 8. Natural sand. Relationship between the maximum force applied and the fracture energy.

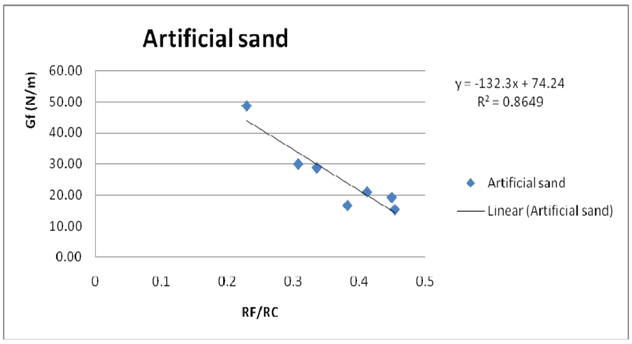


Figure 9. Artificial sand. Ratio between RF/RC and the fracture energy.

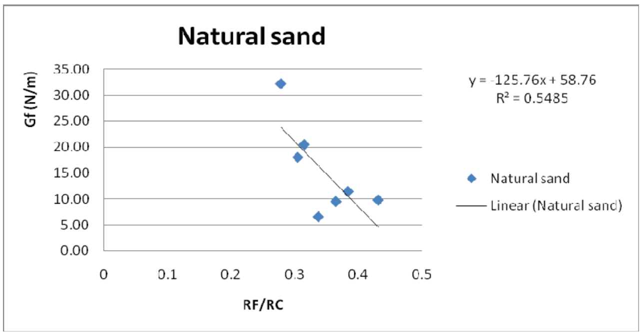


Figure 10. Natural sand. Ratio between RF/RC and the fracture energy.

4 MASONRY SPECIMENS

Four types of masonry specimens were considered:
– W11MC, clay masonry units 30x20x11 cm, mortar type M5_C_A, with cement and artificial sand in a proportion by volume of 1:4;
– W11MHT, clay masonry units 30x20x11 cm, mortar type M2_C+HT_A, cement, air-lime and artificial sand in a proportion by volume of 1:1:7;
– W15MC, clay masonry units 30x20x15 cm, mortar type M5_C_A, with cement and artificial sand in a proportion by volume of 1:4;
– W15MHT, clay masonry units 30x20x15 cm, mortar type M2_C+HT_A, cement, air-lime and artificial sand in a proportion by volume of 1:1:7

The masonry specimens were evaluated by laboratory tests to calculate the Young's modulus, compressive and flexural strength. In accordance with EC6 [4] a theoretical–experimental assessment was also made to evaluate the shear strength.

4.1 Compressive strength

The compressive strength of the masonry specimens were determined by NP EN 1052-1 [11] and included the specimens: W11MC and W11MHT. Three specimens were taken from each sample. Figure 11 shows the compressive strength test and the results are presented in Table 9, where s is the standard deviation.

The masonry sample W11MC, showed characteristic compression strength, f_k, about 60% higher than that obtained for the test specimen W11MHT. The masonry samples W11MC showed higher values of Young's modulus in relation to those obtained for the test specimens W11MHT in about 128%. These results demonstrate that the mortar M2_C+HT_A, provides the best ability for masonry to accommodate deformations, because it showed a significant reduction in Young's modulus of specimen W11MHT. However there was a decrease in compressive strength, although much less marked than that observed for the Young's modulus.

Table 9. Compressive strength and Young's modulus.

Masonry specimens	Compressive strength (N/mm^2)			Young's modulus (N/mm^2)	
	Mean	s	Characteristic	E	s
W11MC	0.996	0.192	0.8	2006	254
W11MHT	0.667	0.192	0.5	879	47

4.2 Flexural strength

The flexural strength of the masonry specimens were determined by NP EN 1052-2 [12] and included the specimens: W11MC, W11MHT, W15MC and W15MHT. Three specimens were taken from each sample. The Figure 12 shows the flexural strength test and the results are presented in Table 10.

Table 10. Flexural strength.

Masonry specimens	Flexural strength		Characteristic flexural strength	
	f_{x1} (N/mm^2)	f_{x2} (N/mm^2)	f_{xk1} (N/mm^2)	f_{xk2} (N/mm^2)
W11MC	0.211	0.442	0.2	0.3
W11MHT	0.272	0.431	0.2	0.3
W15MC	0.487	0.580	0.3	0.4
W15MHT	0.221	0.424	0.2	0.3

The variations in results obtained for the flexural strength with the change of type of mortar, are either zero or about 0.1 N/mm^2. These results demonstrate that the mortar M2_C+HT_A, provides with the masonry best ability to accommodate deformations, because it showed a significant reduction in the Young's modulus of specimens were compared with mortar type M2_C+HT_A, without significantly changing the flexural strength.

Figure 11. Compressive strength

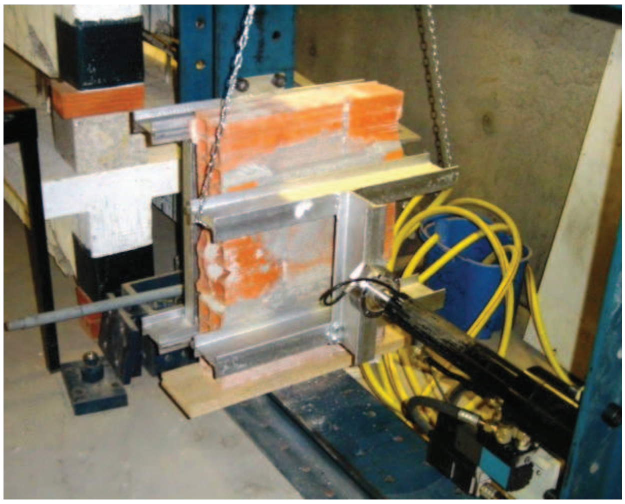


Figure 12. Flexural strength

4.3 Theoretical-experimental evaluation

A theoretical–experimental evaluation was also made in accordance with to EC6 [4] expressions, following the experimental determination of mechanical characteristics of wall components. The coefficients used were for the most appropriate type of brick produced in Portugal. With shear strength only a theoretic evalution was included, however an evaluation - the experimental evaluation is currently underway. The Table 11 summarizes the results obtained. The experimental results and theoretical-experimental findings, obtained for the characteristic compressive strength of the masonry specimens are very similar. By contrast evaluations for the Young's modulus were very different, especially for masonry type W11MC.

Table 11. Theoretical-experimental evaluation.

		W11MC	W11MHT	W15MC	W15MHT
Characteristic compressive strength $f_k = K f_b^{0.65} f_m^{0.25}$ (N/mm^2); K=0.4	Experimental	0.8	0.5		
	Theoretical	0.8	0.6	0.9	0.7
Young's modulus $E = 1000 \times f_k$ (N/mm^2)	Experimental	2006	879		
	Theoretical	800	600	900	700
Characteristic shear strength EC6; § 3.6.2; Equation 3.5 (N/mm^2)	Experimental				
	Theoretical	0.1	0.1	0.2	0.1

5 CONCLUSIONS

For the clay masonry units the shells thickness and the maximum percentage of perforations did not meet the requirements of the National Annex of EC6 [4]. They also showed high levels of water absorption. The compressive strength, showed low values when compared with tabulated values and reference values provided by manufacturers.

From the study done about mortars compositions according to the type of sand we can conclude that mortars made with natural sands always led to better behaviour when subjected to compression and flexural tests.

About the air content of mortars it was found that when we increase compressive strength class, we obtained a decrease in air content level. On the influence of the sand types used it was not possible to draw a general conclusion, but with cement mortars with artificial sand we obtained higher air content values when compared to cement mortars in the same class. In the „mixed“ mortars it was found that for the same type of mortars and same kind of resistance, the natural sand mortars had higher air content values than artificial sand mortars. The ready-to-use mortars had both an air content above the average of the traditional mortars values, which is justified by the incorporation of air entrainers.

From the analysis of shrinkage in mortars, we can conclude that cement mortars have higher shrinking when compared to „mixed“ mortars, and we also observed that the higher the binder quantity is, the greater is the shrinkage value for all mortars studied. In the mixed mortars there were higher values of shrinkage, owing to the greater amount of water used in these compositions when compared with cement mortars. The ready-to-use mortars showed a lower shrinkage compared to traditional mortars, which is related to a lower weight loss (through water evaporation) during the time that the test took place. Such behaviour seems to arise from the fact that these workability mortar values are obtained through other methods, such as: air entrainers and not through water addition, leading to a decrease in binder dosage and contributing to shrinkage reduction.

The fracture energy parameter calculated in the studied mortars, proved to be quite enlightening when we compared the mortars made with different sands. There was higher fracture energy in all artificial sand mortars, compared to natural sand mortars of the same class. This is due to the increased artificial sand particles adherence to the cement paste that leads to an increased final displacement, and therefore a higher fracture energy. It was not possible to draw a conclusion about the influence of different types of binder, but it was possible to find a very direct relationship between applied load and the value of fracture energy calculated when the analyzed mortars were produced with the same type of sand. A similar correlation can also be found between the ratio of flexural/compressive strength (ductility) and the fracture energy calculated.

For the masonry specimens the results demonstrate that the „mixed“ mortars provide a better ability to accommodate the deformations, because they showed a significant reduction in the Young's modulus of specimens. However there was a decrease in compressive strength, although much less marked than that observed for the Young's modulus. The variations in results obtained for the flexural strength with the change of type of mortar, or are zero or very small.

The experimental and theoretical-experimental results, obtained for the characteristic compressive strength of the masonry specimens are very similar. In contrast those two types of evaluation led to values for the Young's modulus that demonstrate significant differences.

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