INFLUENȚA TIPULUI DE LIANT ŞI NISIP ASUPRA CARACTERISTICILOR MORTARELOR DE ZIDĂRIE

INFLUENCE OF TYPE OF BINDER AND SAND ON THE CHARACTERISTICS OF MASONRY MORTARS

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This study deals with the characterization of masonry mortars produced with different binders and sands. Several properties of the mortars were determined, like consistence, compressive and flexural strengths, shrinkage and fracture energy. By varying the type of binder (Portland cement, hydrated lime and hydraulic lime) and the type of sand (natural or artificial), it was possible to draw some conclusions about the influence of the composition on mortars properties. The results showed that the use of Portland cement makes the achievement of high strength classes easier. This was due to the slower hardening of lime compared with cement. The results of fracture energy tests showed much higher values for artificial sand mortars when compared with natural sand ones. This is due to the higher roughness of artificial sand particles which provided better adhesion between sand and binder.

***Keywords:** Masonry, composition, D.a. mortar, D.a. Portland cement, D.a. lime, D.d. sandstone*

1. Introduction

The formulation of masonry mortars influences their characteristics either in fresh and hardened state and should be well studied. Related with fresh state, the evaluation of consistence is the most important characteristic in order to allow a good application. Concerning hardened state the most important characteristics are compressive and flexural strength, and shrinkage. Although not common, the determination of fracture energy is also an important characteristic to be evaluated, since this may provide interesting information regarding ductility and may be useful for numerical modelling.

Ordinary Portland cement (OPC), natural hydraulic lime (NHL) and hydrated lime binders were considered to form a spectrum of related materials. The hydraulicity of these binders, or their ability to set under water, is dependent on the amount of clay which is either added during cement manufacture, or in the case of NHL present as impurity in the parent limestone [1]. OPC and NHL mortars set and harden by complex hydration reactions with carbonation (the absorption of CO_2 from the atmosphere and its reaction with calcium hydroxide forming new calcium carbonate) making some contribution to strength gain. Hydrated lime, also known as air lime [2], is not at all hydraulic. Mortars composed of hydrated lime and sand set by loss of water and then hardens entirely by carbonation.

Sand constitutes bulk of the mortar volume [3]. Composition of sand and its grading can influence the characteristics of mortars in fresh as well as in hardened state. Drew and Braj [4] observed that the water-cement ratio is the largest single factor affecting the compressive strength of mortar irrespective of different types of sand and sand grading. Van Balen and Van Gemert [5] examined some properties of fresh mortar and observed that for a given consistency, mortars with very fine sand required up to 50 % more water than similar mortars having normal sand grading. Reddy and Gupta [3] found that for a given consistency, mortar with fine sand requires more water, compressive strength decreases and drying shrinkage increases.

Benabed et al [6] studied the rheological and mechanical properties of self-compacting mortars made with various types of sands: crushed sand, river sand, dune sand and a mixture of different sands. The experimental results indicate that the rheological properties and mechanical strength has improved in mixtures made with crushed and river sands but has decreased in mixtures with crushed and dune sands especially for higher dune sand content.

The aim of the present study was the characterization of typical masonry mortars properties. The use of natural and artificial sands was tested. Different binders were tested: cement, hydrated and hydraulic lime. The compositions of the mortars were established in order to achieve the strength classes M2.5, M5 and M10, as defined in [7].

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2. Raw materials, mortar compositions and test procedures

2.1. Raw materials

The selected cement was a Portland-limestone one, CEM II B-L 32.5N [8], the most commonly used in Portugal. It has a density of 3150 kg/m^3 and an apparent density of 1200 kg/m^3. The natural hydraulic lime used was a NHL 5 one [9], with a density of 2600 kg/m^3 and an apparent density of 600 kg/m^3. The hydrated lime used was a CL 90 one [9], with a density of 2000 kg/m^3 and an apparent density of 450 kg/m^3.

Two commercial available common sands (artificial, A, and natural, N) were selected, both conform to EN 13139 [10]. The particle size distribution curves, determined according to EN 933-1 [11], are presented in Figure 1. As it can be seen by observing Figure 1, the selected sands are finer ones and their grading curves may be considered similar, both showing an average particle size near 0.5 mm. The artificial sand was a crushed granitic one and has a density of 2660 kg/m^3 and an apparent density of 1493 kg/m^3. The natural sand was a rolled river one and has a density of 2500 kg/m^3 and an apparent density of 1540 kg/m^3.

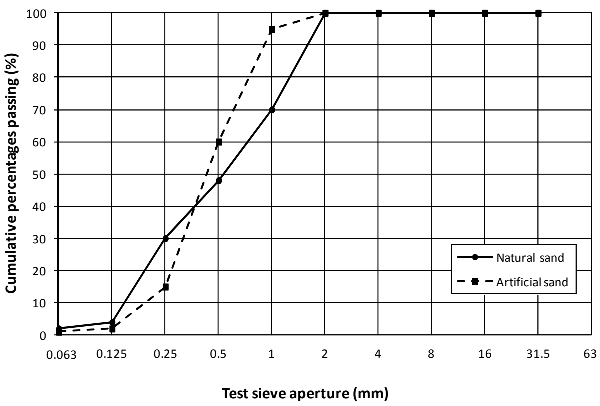

Fig. 1 – Natural and artificial sand grading curves

2.2. Mortars compositions

Different mortar compositions were studied, using three types of binder (cement, air lime and hydraulic lime) and two types of sands (artificial and natural). The compositions were established in order to fulfil the strength classes M2.5, M5 and M10, as defined in [7]. The mortars were made with a standard consistence (160-170 mm) [12], using whatever water was needed for that. Table 1 presents the mortars composition used where C referrers to cement, HL to hydraulic lime, AL to air lime and W/B is the water binder ratio by weight. The adopted mnemonic for mortars consist on the strength class (M2.5, M5 or M10), followed by the binder type (C, C+HL, C+AL), and, after, by the type of sand (artificial (A) or natural (N)).

2.3. Test procedures

The mortars characteristics were evaluated by laboratory tests. For fresh state the consistence was evaluated. For hardened state the compressive and flexural strengths, the shrinkage and the fracture energy were evaluated.

The flexural and compressive strengths were determined following EN1015-11 [13]. After mixing, all specimens were maintained at 20ºC (of temperature) and 95% of moisture content. The specimens were demoulded at two day of age followed by maintaining in the climatic chamber for more 5 days. After that, they were exposed at laboratory curing conditions (temperature of 20ºC and moisture content around 65%) until the date of testing.

The flexural strength of the tested mortars was determined by three point loading of hardened moulded mortar prism specimens with 40x40x160 mm to failure. The compressive strength of the mortars was determined on the two parts resulting from the flexural strength test. For flexural strength, three prismatic specimens were tested and for compressive strength, six specimens were tested, both at 28 days of age.

Table 1

Mortars composition

Mortar	Composition in volume parts	C (kg)	HL (kg)	AL (kg)	Sand (kg)		Water (dm^3)	W/B
					A	N		
M2.5_C_A	1:6	1.20			8.96		1.51	1.26
M2.5_C_N	1:6	1.20				9.24	2.03	1.69
M5_C_A	1:4	1.20			5.98		1.38	1.15
M5_C_N	1:4	1.20				6.16	1.36	1.13
M10_C_A	1:3	1.20			4.48		1.03	0.86
M10_C_N	1:3	1.20				4.62	1.00	0.83
M2.5_C+HL_A	1:1:7	1.20	0.60		10.43		2.52	1.40
M2.5_C+HL_N	1:1:7	1.20	0.60			10.78	2.05	1.14
M5_C+HL_A	1:1:5	1.20	0.60		7.45		1.73	0.96
M5_C+HL_N	1:1:5	1.20	0.60			7.70	1.54	0.86
M2.5_C+AL_A	1:1:7	1.20		0.45	10.43		2.40	1.45
M2.5_C+AL_N	1:1:7	1.20		0.45		10.78	2.25	1.36
M5_C+AL_A	1:1:5	1.20		0.45	7.45		1.85	1.12
M5_C+AL_N	1:1:5	1.20		0.45		7.70	1.46	0.88

The shrinkage of mortars was determined according the specification LNEC E398 [14], which is based on the RILEM CPC 9 recommendation [15]. The shrinkage deformations of each 40x40x160 mm specimen (mixed, moulded, demoulded and conserved according to the procedure already described for flexural and compressive strength specimens) were measured using a length comparator, with a sensitivity of 1 μm, and gage studs on the end sections of the mortar prisms. Stability of the length comparator was checked by a reference invar bar. The length of the specimens was measured after the demoulding and until the age of 90 days.

The fracture energy of mortars was determined carrying out three points bending tests according to recommendations (RILEM_TC50-FMC [16]) using 850x100x100 mm notched beam specimens. At 28 days of age, in the pre-test preparation phase of beam specimens, a notch of 6 mm width and 30 mm depth was sawn in a beam face parallel to the casting direction. All the tests were performed under displacement control using closed loop equipment with a mid-span deflection increase at a constant rate of 0.36 mm/min. During the flexural tests the mid-span deflection and the corresponding applied force were measured, which allows to evaluate its behaviour. Three specimens were tested for each mortar composition at 28 days of age.

3. Experimental results and analysis

3.1. Flexural and compressive strengths

Flexural and compressive strength tests were performed at 28 days of age. The obtained results are presented in Table 2, where: CoV, is the coefficient of variation, and f_{fm}, f_{cm}, are, respectively, the average flexural and compressive strengths. Using cement as binder it was possible to reach the classes M2.5, M5 and M10. For the blended cement-hydraulic lime mortars the class M10 was not possible to achieve. With blended cement-hydrated lime mortars only the class M2.5 was obtained. Similar results of compressive strength were obtained by other authors [17-19]. As the tests were performed at 28 days, it is possible that the mortars with hydrated lime were not fully carbonated.

Observing the obtained results one can conclude that almost mortars made with the same composition and binder and containing natural sand have slightly higher values than the artificial sand mortars. This fact is mainly concerned with the higher 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 for the mortar made with artificial sand than for the mortars made with natural sand. Exceptions related to better performance of natural sand were detected for flexural strengths of mortars M2.5_C+HL_N, M2.5_C+AL_N and M5_C+AL_N. These compositions (with natural sand N) show smaller flexural strength than the ones containing artificial sand. This may be due to the inherent dispersion of the flexural test results that, as usual, was higher than for compressive strength test results. The water/binder ratio is, as it is well known, an important parameter strongly affecting the mechanical strength, as it can be seen for compressive strength in Figure 2, where "C" represent the cement based mortars and "C+HL" and "C+AL" the blended ones, containing, respectively, cement plus hydraulic lime (HL) or cement plus air lime (AL). As this ratio is higher, the results obtained for the compressive strength were lower. The variation follows approximately Abram´s law demonstrated in 1918 [20]. The equations are different for cement mortars and mixed cement-lime mortars. In this last case the mean squared error (MSE) is higher than for cement mortars. It was possible to obtain higher compressive strengths with cement mortars when compared with mixed cement-lime mortars with the same water/binder ratio.

Table 2

Flexural and compressive strengths.

Mortar	Desired class [7]	Flexural strength (N/mm^2)		Compressive strength (N/mm^2)	
		f_{fm}	CoV (%)	f_{cm}	CoV (%)
M2.5_C_A	M2.5	1.20	5.8	2.70	5.9
M2.5_C_N	M2.5	1.20	9.2	2.80	8.6
M5_C_A	M5	1.90	6.8	5.65	8.1
M5_C_N	M5	2.70	8.5	7.00	6.4
M10_C_A	M10	2.45	1.6	10.80	5.4
M10_C_N	M10	3.10	12.3	11.30	6.9
M2.5_C+HL_A	M2.5	1.25	7.2	3.30	8.2
M2.5_C+HL_N	M2.5	1.20	7.5	3.30	6.7
M5_C+HL_A	M5	1.60	2.5	5.25	4.2
M5_C+HL_N	M5	1.65	4.2	5.35	2.8
M2.5_C+AL_A	M2.5	1.15	2.6	2.55	3.5
M2.5_C+AL_N	M2.5	0.90	21.1	2.65	7.2
M5_C+AL_A	M5	1.90	1.1	4.70	4.0
M5_C+AL_N	M5	1.40	7.9	4.70	2.1

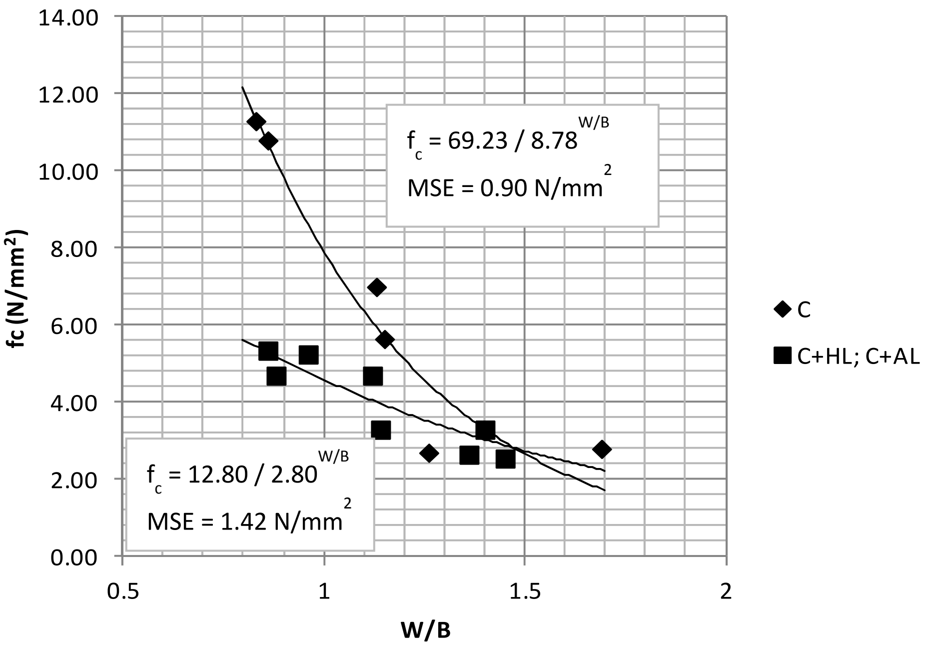

Fig. 2 – Variation of the compressive strength with the water/binder ratio.

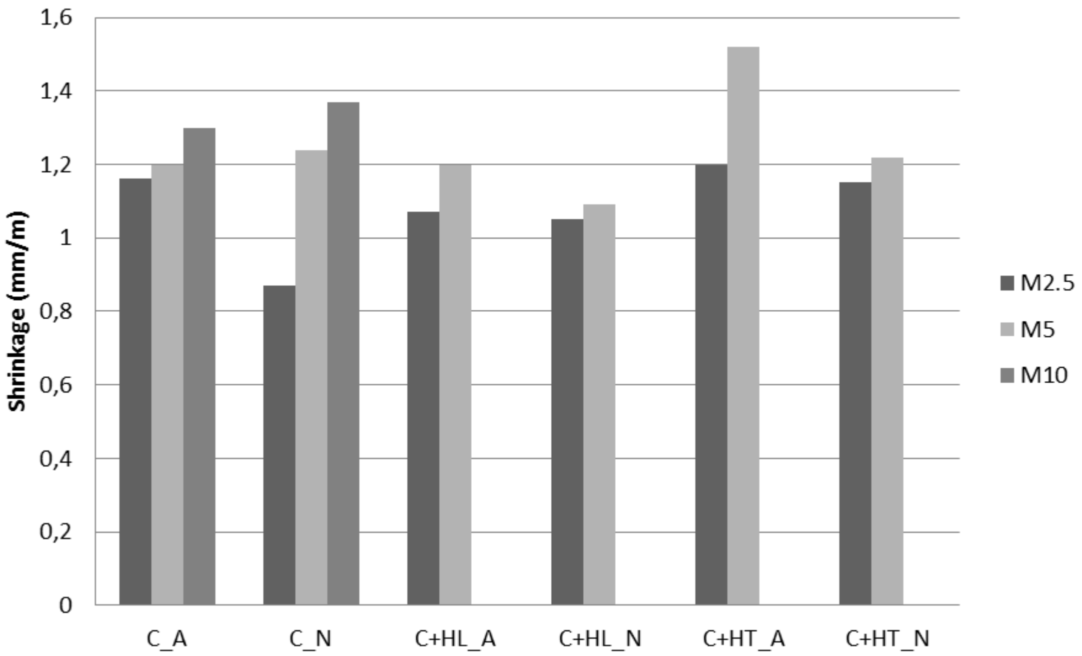

Fig. 3 – Shrinkage values at 90 days of age.

3.2. Shrinkage

The results presented in Figure 3 are the average of the measures tacked on three specimens at 90 days of mortars age. Although the tests have been carried out with controlled temperature and humidity, some long term variations related to climate conditions changing in the test facilities, were found.

For all mortars, it was observed that the higher were the mortars strength class (therefore the amount of binder), the higher was the value of shrinkage. The mortars that had higher value of shrinkage were the cement plus hydrated lime, followed by the cement mortars, and finally the cement plus hydraulic lime mortars. The same results were obtained by Reddy and Gupta [3], using similar sands. In our study, mortars containing artificial sand and made with the same composition and binder have slightly higher values of shrinkage than the natural sand mortars. This fact is mainly concerned with the higher amount of water used in the composition of the mortar made with artificial sand.

3.3. Fracture energy

The fracture energy of mortars was determined by the specification RILEM_TC50-FMC [16]. The average of three specimens results are presented in Table 3, where: δ_0, is the final deformation at failure; F_{max}, is the maximum applied load; and G_f is the fracture energy.

Table 3

Fracture energy

Mortar	δ_0 (mm)	F_{max} (kN)	G_f (N/m)
M2.5_C_A	0.44	0.23	19.24
M2.5_C_N	0.28	0.30	9.76
M5_C_A	0.70	0.37	28.81
M5_C_N	0.28	0.32	11.44
M10_C_A	0.87	0.77	48.72
M10_C_N	0.59	0.82	32.23
M2.5_C+HL_A	0.49	0.23	16.63
M2.5_C+HL_N	0.27	0.26	9.48
M5_C+HL_A	0.73	0.41	29.96
M5_C+HL_N	0.48	0.46	20.49
M2.5_C+AL_A	0.49	0.16	15.35
M2.5_C+AL_N	0.18	0.15	6.53
M5_C+AL_A	0.55	0.29	20.97
M5_C+AL_N	0.47	0.34	18.02

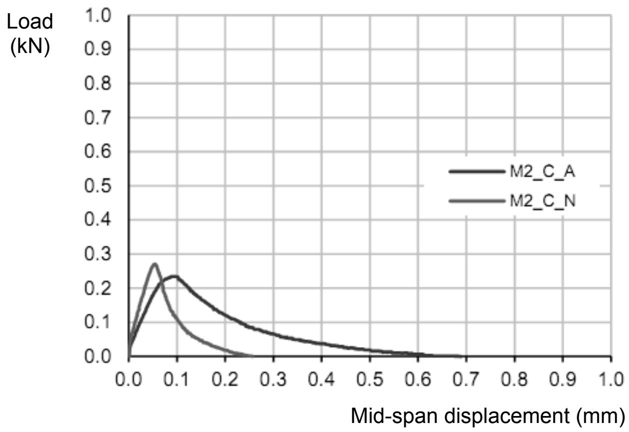

Fig. 4 - Average values of fracture energy for cement mortars of strength class M2.5.

The analysis of the results shows that the artificial sand mortars, for all classes and all types of binders, have greater value of fracture energy. Figures 4, 5 and 6 also show the differences in the fracture energy for cement mortars of strength class M2.5, M5 and M10, respectively. We only present the flexural behaviour of cement mortars once the blended ones have shown identical tendencies.

For mortars belonging to 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 above compared with the natural sand mortars. After application of the maximum load, during softening, it is observed that the artificial

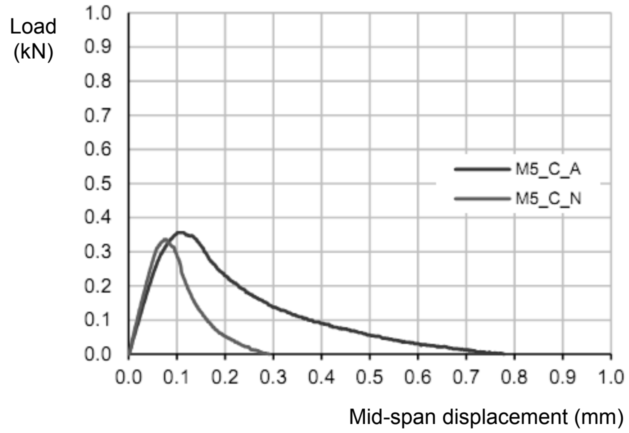

Fig. 5 - Average values of fracture energy for cement mortars of strength class M5.

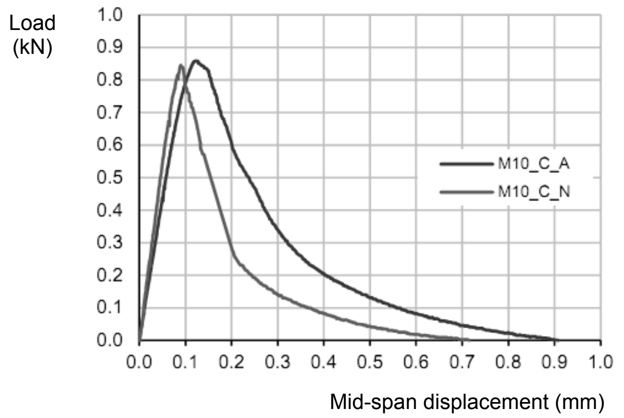

Fig. 6 - Average values of fracture energy for cement mortars of strength class M10.

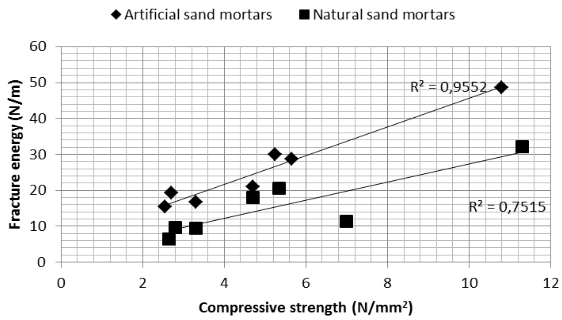

Fig. 7 – Variation of fracture energy with compressive strength of the mortars.

sand mortars have a better load capacity absorption, reaching a displacement at the failure much higher than the natural sand mortars. The displacement of the mortars was not too much different when the maximum load is acting, but at the time of failure the displacement occurred in the artificial sand mortars is sometimes the double of that obtained in natural sand mortars. This fact should be connected with the adhesion between the artificial sand and the binder. In this case, it is much higher when compared with what happens in mortars containing natural sands. This difference in the adhesion is due to the higher roughness of the artificial sand grains when compared with the natural ones. Figure 7 shows that the relation between the compressive strength and the fracture energy of the mortars seems to be approximately linear. However the linear correlation coefficient (R2) is higher for artificial sand mortars than for natural sand mortars.

4. Conclusion

From the presented study, it seems that it is possible to conclude that the types of binder and sand may have a higher influence in the mortars characteristics. The use of Portland cement makes easier the achievement of high strength classes. This is due to the carbonation of lime that develops slower than the hydration of cement. The type of sand affects mortars flexural and compressive strengths. The mortars made with natural sand led to higher strength in most of the cases. This is due to the lower water/binder ratios used in natural sand mortars, in order to maintain the consistence.

The shrinkage increased with the amount of binder. This result was not influenced by the type of binder. The results of fracture energy tests showed much higher values for artificial sand mortars when compared with natural sand ones. This is due to the higher roughness of artificial sand particles which provided better adhesion between sand and binder paste.

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