Mechanical Characterization for Mortar for Masonry

Nuri Batista
Department of Civil Engineering, University of Minho,Campus de Azurém, 4800-058 Guimarães, Portugal

M F Paulo Pereira
Department of Civil Engineering, University of Minho, Campus de Azurém, 4800-058 Guimarães, Portugal

José B. Aguiar
Department of Civil Engineering, University of Minho, Campus de Azurém, 4800-058 Guimarães, Portugal

Abstract

The Eurocode 6 defines classes of mortars resistance which are based on the minimum compressive strength of mortar at 28 days after casting and suggests reference compositions for obtaining such classes. To incorporate in the National Annex of Eurocode 6, we have studied different mortar compositions usually adopted in Portugal. The mortars composition was based on the Bolomey's formula.

The mechanical characteristics of the mortar, were evaluated by laboratory tests: consistence and air content (fresh mortars); compressive and flexural tensile strength, Young's modulus, shrinkage and fracture energy (hardened mortars).

In the first phase of the study were considered six different sands: three artificial (AE - left to the limit - very fine sand, A - within the limits and AD - right to the limit - very coarse sand) and three natural (NE - left the limit - very fine sand, N - within the limits and ND - the right to limit - very coarse sand).

The second phase of the study was only with the artificial and natural sand within the limits, A (artificial sand) and N (natural sand). For the same classes of resistance, the natural mortar of sand has almost better results than mortars of artificial sands; the mortars whose binder was only the cement, showed quite reasonable resistance, as well as the mortar in which was used the hydraulic lime; the mortar of cement and hydrated lime were the ones who presented lower resistance. The mortar of artificial sand has higher values of fracture energy compared to mortar with natural sand.

Keywords

Mortar, Sand, Masonry, Fracture energy

1. Introduction

The building envelop in Portugal is usually made by masonry walls, with enclosure and infill functions. These walls are one of the most relevant subsystems in buildings, separating the indoor and outdoor environment, and having a decisive role in the 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. This subsystem features insufficient performance and severe damages (typically around 25% of all building damages). Masonry walls are a subsystem incorporating elements with very high costs, such as: finishings, installations and windows. The walls represent the largest value of materials, being around 0.3 m3/m2 of in plan area, and corresponding to about 35% of the building weight. The walls also interact with the production of almost other subsystems, controlling the execution of works and the building sequence of different tasks.

The total masonry cost in Portugal is about 8.5 to 10.5 % of the total building cost, making the total annual value of masonry works about 1275 M Euros. With the additional interaction with renderings and other finishings, and windows, the walls interact directly or indirectly with an annual value of 3825 M Euros. Therefore, masonry walls have a major economical importance and contribute significantly for the building performance, usually affected by damage from deficient quality of materials, workmanship, design and detailing, and the clear definition of a responsible technician.

Non-load bearing masonry walls are subjected to direct actions, such as self-weight, wind and earthquakes, and indirect actions, such as shrinkage, expansion and deformation of supports.

In the last years, a growing interest has been observed in the seismic vulnerability of buildings, related to insufficient resistance, inadequate materials and building techniques, changes to the original design and lack of maintenance. Reinforced concrete structures have been for long studied and adequate codes have been around for decades. But, for masonry, only with the appearance of EC6 and EC8 it is possible to state that a proper legal framework is available. Even if masonry infills have no load-bearing function, they contribute significantly to the seismic behavior of buildings. Therefore, adequate structural performance is needed, avoiding the occurrence of severe damage in the walls in plan, with very large economical losses, and the out of plan expulsion, which additionally represents a large risk for human life.

The global aim of this study is the performance's evaluation of building's envelope face to earthquakes, but in this manuscript we only presented a small part about masonry's mortar.

2. Objectives

The aim of this study is the mechanical characterization of the mortar compositions usually adopted in Portugal (where the usage of lime is lost), taking into account the European testing standards and the difference between the properties found in the laboratory and in situ. These tests will be directly incorporated in the National Annex of Eurocode 6.

3. Development Methodology

The Eurocode 6 defines mortars resistance classes which are based on the minimum compressive strength of mortar at 28 days after casting and suggests reference compositions for obtaining such classes.
To incorporate in the National Annex of Eurocode 6, we have studied different mortar compositions usually adopted in Portugal. The mortars composition was based on the Bolomey's formula. The mechanical characteristics of the mortars were evaluated by laboratory tests.

Fresh mortars:	Consistence and air content
Hardened mortars:	Compressive and flexural tensile strength;
	Young's modulus;
	Shrinkage;
	Fracture energy.

For this study we considered three tasks:

- Sand's grading for mortar for masonry;
- Composition proposal;
- Fracture energy.

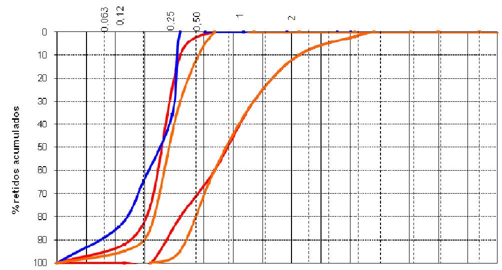
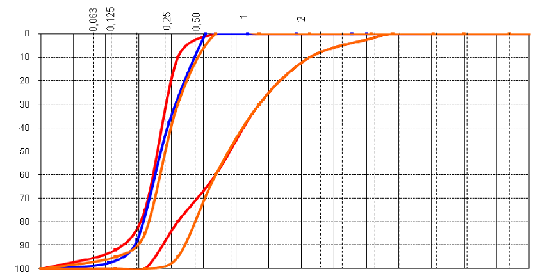
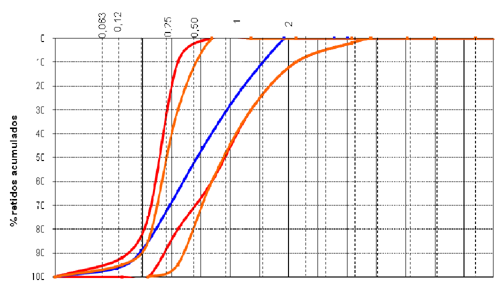
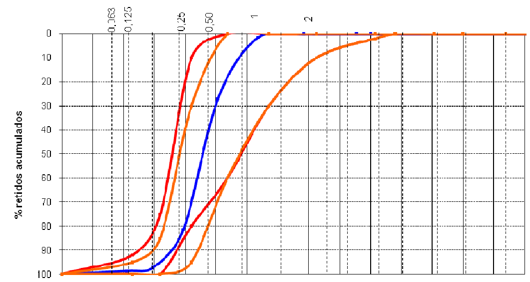
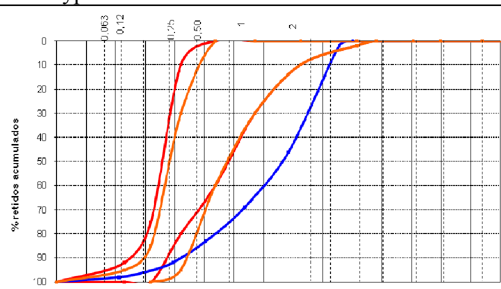
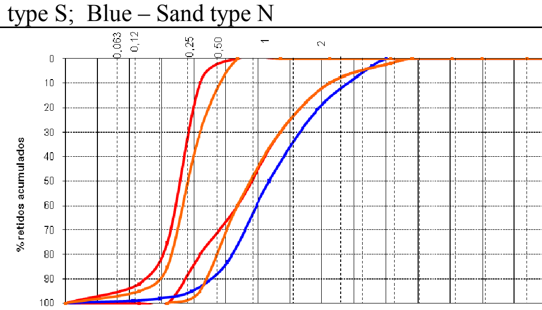
3.1. Sand's Grading for Mortar for Masonry

In accordance with the limits imposed by BS1200 were considered six different sands:

Three artificial sands	AE - left to the limit (very fine sand); A - within the limits; AD - right to the limit (very coarse sand);
Three natural sands	NE - left the limit (very fine sand) N - within the limits; ND - the right to limit.

We set the cement as binder, class of resistance M5 (1:4) and consistence 16 cm. The mortars were tested to flexural and compressive strength, in accordance with EN 1015-11: determination of flexural and compressive strength of hardened mortar, followed by the test procedure and conditions for curing of the samples referred, rehearsing the samples at 7, 14 and 28 days.

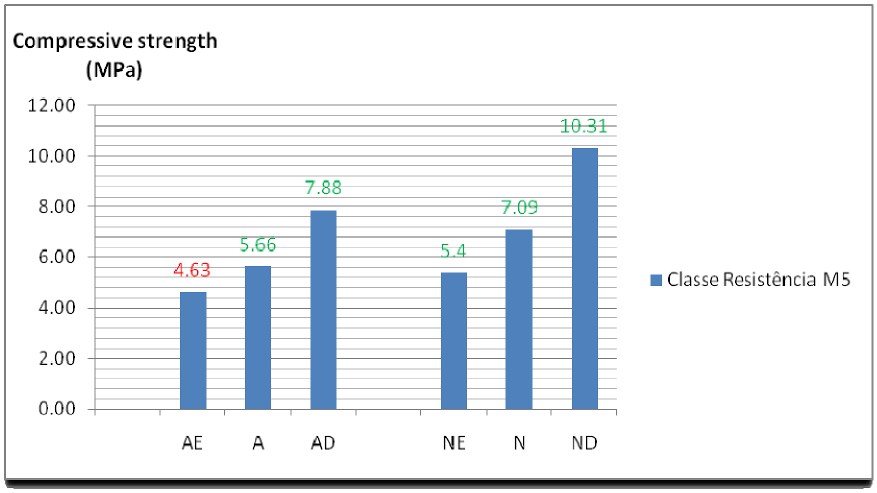
Table 1: Sand's Grading in Accordance by BS1200

	
Red – Limits of a sand type G; Orange – Limits of a sand type S; Blue – Sand type AE	Red – Limits of a sand type G; Orange – Limits of a sand type S; Blue – Sand type NE
	
Red – Limits of a sand type G; Orange – Limits of a sand type S; Blue – Sand type A	Red – Limits of a sand type G; Orange – Limits of a sand type S; Blue – Sand type N
	
Red – Limits of a sand type G; Orange – Limits of a sand type S; Blue – Sand type AD	Red – Limits of a sand type G; Orange – Limits of a sand type S; Blue – Sand type ND

3.1.1. Results

As we can see on Graph 1, the mortar of sands located on the left size of the zone imposed by BS1200 (AE and NE), results show low-resistance when compared with the mortar of sands on the right zone of the limits (AD and ND).

Graph 1: Compressive Strength



This is due to the amount of water that was necessary to add to the mixture of the finest sand in order to obtain the desired consistence (16 cm), unlike the mortar of sands ND AD that needed much less water to achieve it.

3.2. Composition Proposal

In this task of the study only the artificial and natural sand within the limits imposed by BS1200 were considered.

To incorporate in the National Annex of Eurocode 6, we have studied different mortar compositions usually adopted in Portugal, with the following resistance classes: M2, M5 and M10.

In Table 2, we can see the EC6 composition proposal and in the Table 3 the study proposal.

Table 2: EC6 Composition Proposal

Class	**Composition**				**Compressive strenght 28 days** [MPa]
	Cement	**Hidrated lime**	**Hidraulic lime**	**Sand**	
M20	(Composition by experimental testing)				20.0
M15	1	0 – ¼		3	15.0
M10	1	¼ – ½		4 – 4 ½	10.0
M5	1	½ – 1 ¼		5 – 6	5.0
M2	1	½ – 1 ¼		8 – 9	2.0

Table 3: Study Composition Proposal

Class	Composition				Compressive strenght 28 days [MPa]
	Cement	Hidrated lime	Hidraulic lime	Sand	
M10	1			3	10.0
M5	1			4	5.0
M5	1	1		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

3.3. Fracture Energy

Fracture energy is a fundamental fracture parameter, representing the cracking resistance and fracture toughness of concrete and mortar, and it is generally considered a material property, especially in concrete fracture mechanics and cracking analyses.

Fracture energy can be defined as the amount of energy needed to create one unit area of a crack; in other words, the necessary energy for a crack propagation. The area of a crack can be defined as the projected area on a plan parallel to the main crack direction. [4]

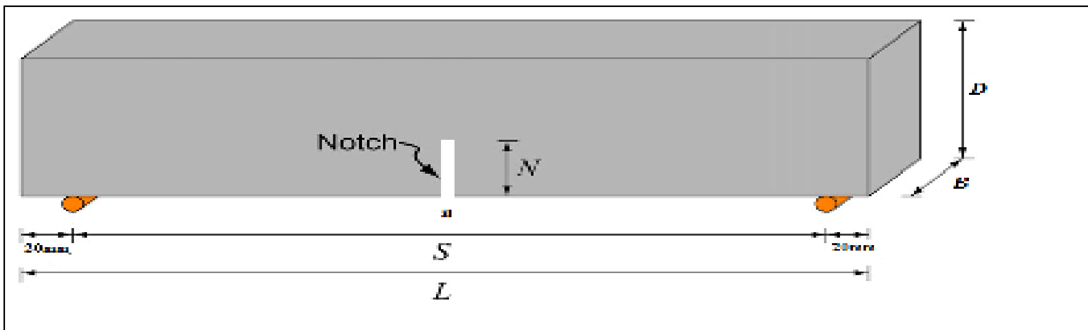
3.3.1. Experiments

3.3.1.1. Materials

The tested mortar was previously described, including a cement mortar with natural sand, (C+N), as well as cement mortar with artificial sand, (C+A). All the tested mortar belongs to class resistance M5.

3.3.1.2. Specimen and test set-up

Figure 1 shows the geometry of the beam. There were tested three specimen of each mortar with 28 days old.



D=100 mm
B=100 mm
L=840 mm
S=800 mm
N=30 mm
a=6 mm

Figure 1: Geometry of the Beam

In Figure 2, we can see the instrumentation performed on specimens and the fracture suffered by them.

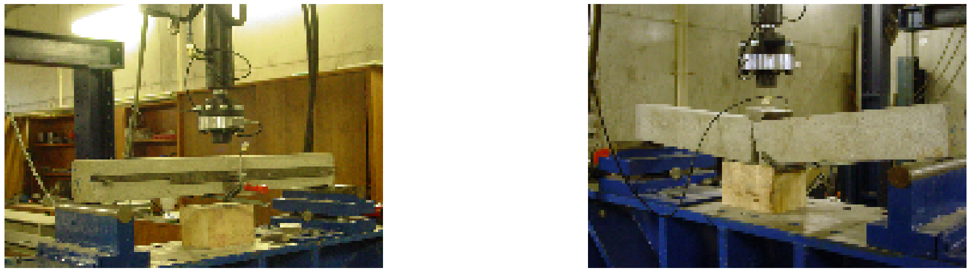


Figure 2: Instrumentation Performed and Fracture of the Specimens

3.3.2. Test results and discussion

The fracture energy was determined by means of three-point bend tests according to the RILEM recommendations for determination of the fracture energy of mortar.

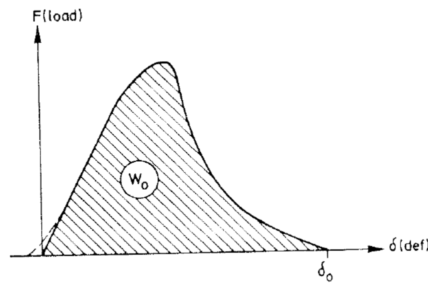


Figure 3: Energy Wo

The fracture energy for each specimen was calculated from the test results based on the following equation:

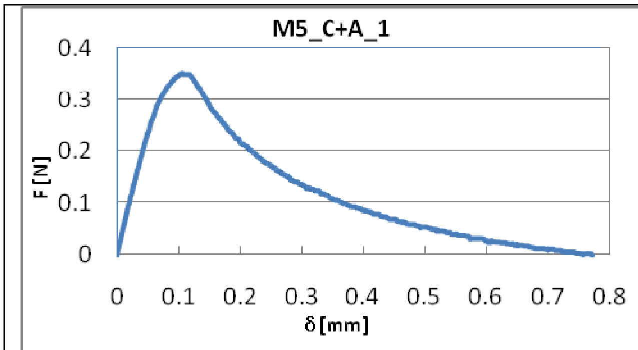
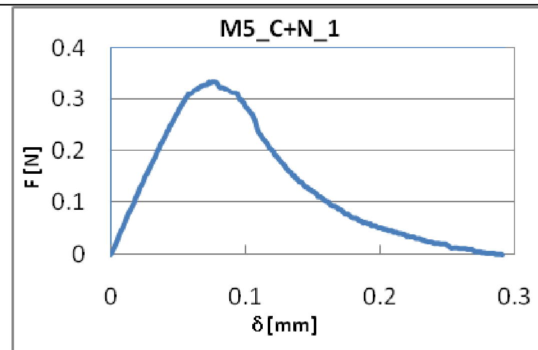
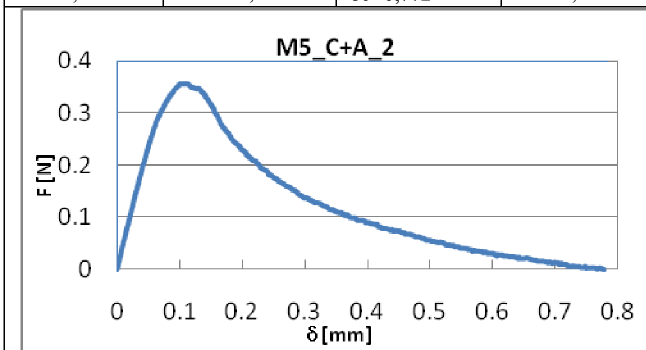
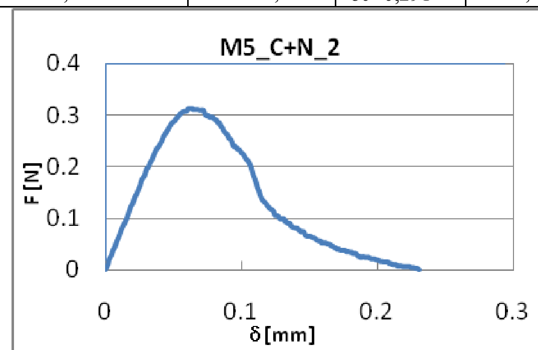
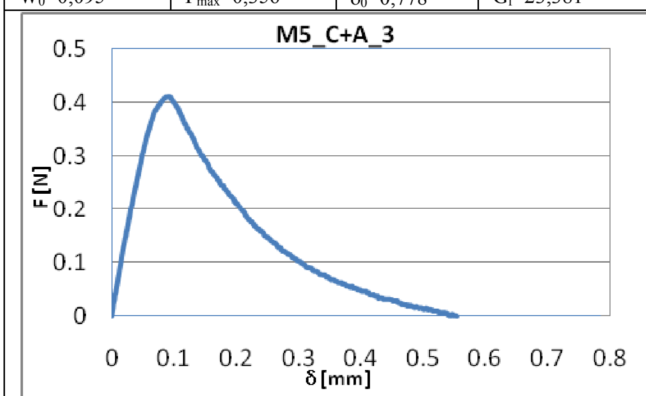
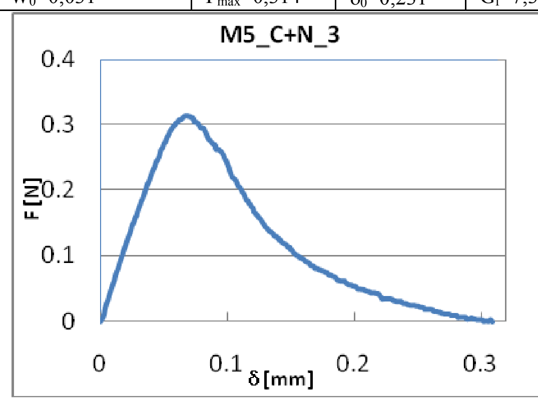
$$G_F = \frac{W_0 + mg\delta_0}{A_{lig}} \quad [N/m \ (J/m^2)]$$

where:

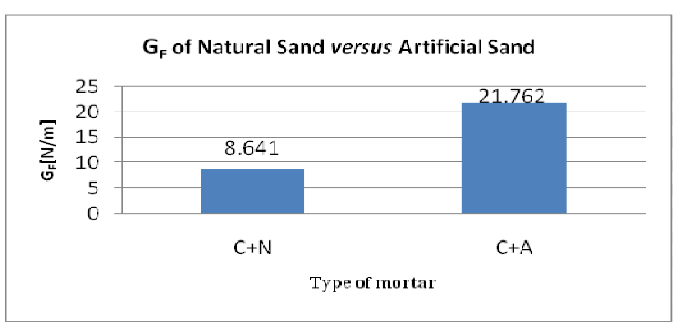
W_o Area according Figure 3 (N/m)
m Weight of the beam between the supports and the weight of the part of the loading arrangement which is not attached to the machine (kg)
g Acceleration due to gravity, 9,.81m/s2
δ_0 Deformation at the final failure of the beam (m)
A_lig Fracture area defined by:[D(B-a)] (m2)

The results for the specimen of cement mortar with artificial sand (C+A) and natural sand (C+N) are presented in Table 4

Table 4:Load-deflection Curves for Beam Specimens of Cement Mortar Class M5

							
W0=0,092	Fmax=0,353	δ0=0,772	Gf=22,956	W0=0,039	Fmax=0,336	δ0=0,291	Gf=9,271
							
W_0=0,095	F_{max}=0,356	δ_0=0,778	G_f=23,381	W_0=0,031	F_{max}=0,314	δ_0=0,231	G_f=7,335
							
W_0=0,083	F_{max}=0,412	δ_0=0,555	G_f=18,954	W_0=0,036	F_{max}=0,312	δ_0=0,31	G_f=9,316

Graph 2: Variation of the Average Energy Fracture of Cement Mortar Class M5 According to the Type of Sand



In Graph 2, when comparing the fracture energy for cement mortar with different types of sand, it can be observed that the mortar of artificial sand has higher values of fracture energy when compared to mortar with natural sand. This is because mortar with artificial sand is more ductility presenting a larger displacement (about 0.7 mm) comparatively to natural sand (about 0,28 mm). The higher force was also registered in artificial sand mortar but the value is approximately equal in both mortars.

4. Conclusions

Based on the results obtained in the study, the following conclusions were reached:

1) The mortar of sand located within the boundaries are showing results closer to the initially class of compressive strength desired;
2) For the same classes of resistance, the mortar of natural sand has almost better results than mortars of artificial sands;
3) The mortars whose binder was only the cement, showed quite reasonable compressive strength, as well as the mortar in which was used the hydraulic lime;
4) The mortar of cement and hydrated lime were the ones who presented lower compressive strength;
5) The mortar of sand located within the boundaries are showing results closer to the initially class of compressive strength desired;
6) For the same classes of resistance, the mortar of natural sand has almost better results than mortars of artificial sands;
7) The mortars whose binder was only the cement, showed quite reasonable compressive strength, as well as the mortar in which was used the hydraulic lime;
8) The mortars of cement and hydrated lime were the ones who presented lower compressive strength.
9) The mortar of artificial sand has higher values of fracture energy compared to mortar with natural sand.

5. References

BS1199 & 1200:1976 Specification for building sands from natural sources.

EN 1015-11:1999 Methods of test for masonry.(1999). Part 11: Determination of flexural and compressive strength of hardened mortar. CEN.

Eurocode 6, Design of masonry structures – Part 1-1: General Rules for Buildings. Rules for reinforced and unreinforced masonry. CEN, prENV 1996-1-1, (1995).

Eurocode 8. (1993). Earthquake Resistance Design of Structures – Part 1: General Rules for Buildings. CEN, prENV 1998-1.

J. L. Barroso de Aguiar. (2007)..*Apontamentos da cadeira de Materiais de Construção I*, "Pedras, Ligantes, Argamassas, Madeiras, Metais",

Manuel F. P. Pereira (2005). Tese de Mestrado, Universidade do Minho, "Anomalias em Paredes de Alvenaria sem Função Estrutural",

P.B. Lourenço and H. Sousa,.(2002). "Seminário sobre Paredes de Alvenaria".

RILEM (1985). Committee FMC 50, Determination of the fracture energy of mortar and concrete by means of three point bending tests on notched beams, Material and Structures.