

TIME INFLUENCE ON THE MECHANICAL PROPERTIES OF ANCIENT MORTARS OF EASTERN SICILY

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Abstract— The study analyses the mechanical properties of the mortar samples collected from the surviving heritage masonry structures in eastern Sicily. The chemical attack was used to determine their composition: extracted purely lime-based binder mortars differ in the sand used according to the ancient recipe. Thus, new mortar samples were constructed to match those collected from the historical buildings. Their mechanical characteristic are, so, determined firstly at 30-60 days of curing and then after very long time of curing (20 years). More than 200 samples were tested under bending and compression. The data were compared each other in order to evaluate the time influence on the mechanical properties.

Keywords—mortar, mechanical characterization, tests, masonry, ancient buildings

I. Introduction

The preservation of valuable ancient or historical buildings, which tend to deteriorate because of the environment [1-10] is a great challenge. Restoration, repair and retrofitting of our heritage must be carried out using materials with chemical and mechanical features similar to the native ones [11-13] when the innovative technologies [14-17] are applied since the effectiveness of the restoring technique applied strongly depends on the properties of the masonry compounds [18-20].

The replacement of the mortar materials is, therefore, encountered during the restoration of monuments [21-24]. However, mechanical properties of original mortars, are often, not fully understood. Historical constructions in Sicily are characterized by the use of stone masonry either as blocks [25] or bricks, taken from the local quarries, and mortar which the aggregate derived by the calcareous stone in the southern part of Sicily and lava stone in the Etna region. The sand was combined with lime putty binder made with quicklime from limestone.

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The most used proportion of the mortar, since antiquity, is represented by one part of binder matrix and three parts of aggregate.

The mechanical properties of the masonry therefore, appear to be strongly affected on the mechanical and physical characteristics of the mortar and little information is available on them so this paper aims to disseminate the results obtained by an experimental study of the mechanical properties cured in room conditions for more than 20 years.

II. CHARACTERIZATION OF ANCIENT MORTARS

A. Composition of the mortar

The historical monumental buildings chosen for the samples collection, were in Giarre a little town in the Etna region.

The samples were then, analyzed to determine the amount and typology of the employed aggregate as well as the percentage of binder matrix. To this aim, a decomposition method based on the acid digestion analysis was adopted according to RILEM TC-167-COM. The aggregate size was determined by means of the ASTM standard of sieve series.

Table I shows the average composition of the ancient mortar and the percentage of lime content obtained:

TABLE I. COMPOSITION OF ANCIENT MORTAR

Source	Sample weight [gr]	Aggregate [%]	Lime [%]
Giarre 1	2600	83.4	16.6
Giarre2	2480	83.7	16.3

The validity of these results was preliminary tested, by determining the grain distribution of new mortar specimens made in laboratory with the same mix design, broken down and tested by the same procedure

B. Composition of the simulated ancient mortars

Direct tests on specimens removed from masonry walls were not possible because of their irregular shape as well as the disturb during extraction. For this reason, the mortars were remade in laboratory.

The hydraulic Mortar found in the historical buildings highlight the use of lime as binder and of two types of sands as the aggregate. They differ each other, because of their peculiar red or black coloration, visible even at naked eye:

Red Sand- a volcanic sand originating from the contact between the Etna fluid lava and soil

Black Sand- a volcanic sand taken from the river bed of the Etna volcano area.

The former is taken along the bed of 'Etna lava flows, the latter along the bed of a torrent located in the upper area of Etna.

According to the Italian standard [26]in force at the time of the specimen preparation (D.M. 20/11/1987), the reconstructed ancient mortars can be classified as in table II.

TABLE II. COMPOSITION OF ANCIENT MORTAR ACCORDING TO DM 1987 AND UNI EN 998-2 STANDARDS

Series	Standard		Composition				Expected Compressive strength
	D.M. 20/1987	UNI EN 998-2	Calc. aggregate	Lava aggregate	Lime	Cement	
			red	black	azole		
A	M4 Hydraulic	M 2.5	-	3		1	2.5 N/mm ²
B	M4 Hydraulic	M 2.5		3		1	2.5 N/mm ²

More than 200 specimens (fig.1) were made together, then kept one day at 20±2 °C 90% room humidity (rh); four days at 20±2 °C 60% rh and then cured at room temperature until the day before testing. Then they were dried in a furnace, at the heating rate of 105°C for 24 hours, cooled at room temperature and, finally, tested.

Two kinds of shapes were chosen for the specimens: 40x40x160 mm prisms and cylinders h=90 mm D=45 mm.

Uniaxial proprieties only have been determined so far: 3-points bending, elastic modulus and compression tests on cubes and cylinders were carried out for 30-60-90-360 days of curing and finally for 20 years. Ten tests were carried out for each series of specimens.



Figure 1. Mortar Specimens: gloabl view

III. TEST CAMPAIGN

A. Specimen instrumentation

LVDT transducers have been used on the specimens for the assessment of the mechanical parameters in play and a load cell of 250 kN capacity was suitably connected to detect the necessary data.

B. Three-point Bending Tests

The bending test is governed by UNI 1052-2 "Method of test for masonry"; 160 mm long specimens have been used.

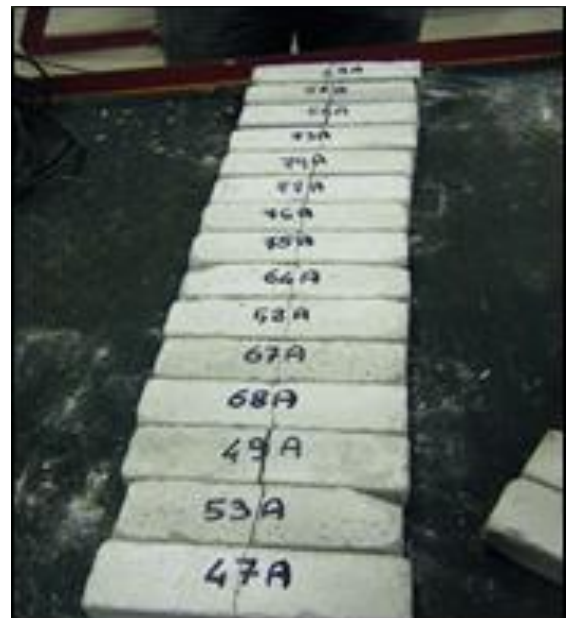


Figure 2. Collapse of the specimen after bending test

The experimental data are summarized in table III in function of the curing time. Red sand aggregate lime mortar (C series) appears stronger than the black sand lime mortar.

TABLE III. MEAN FLEXURAL STRENGTH (N/MM²) VERSUS CURING TIME

Series	30 days	60 days	90 days	1 year	20 years
A	0,43	0,45	0,47	0,44	0,43
B	0,28	0,30	0,37	0,39	0,37

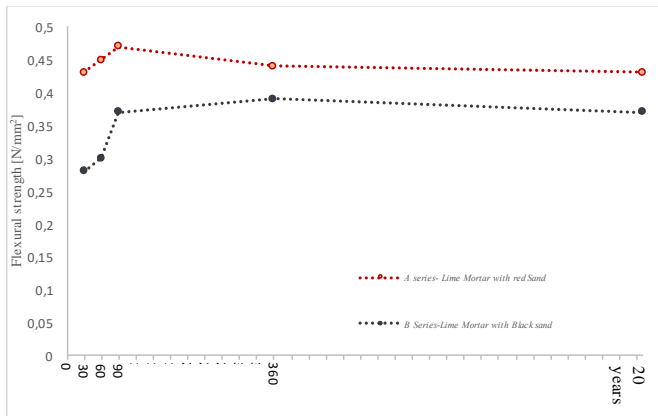


Figure 3. Flexural strength vs curing time

The lime mortar with black or red sand aggregate (fig. 3) is a weaker mortar in respect to the common lavic aggregate (*black sand*). This is due to the very small diameter of the sand grains not capable of developing interlocking. Besides, the time does not seem to be affected. After the initial period of curing (60 days) in fact, only a drop of 3-5% is visible in the specimens.

C. Compression test

The cube specimens (fig. 4) were obtained from the broken parts of the specimen 40x40x40 mm. They were tested in compression under displacement control.



Figure 4. Global view of the specimen for compression tests

The results are shown in table IV:

TABLE IV. MEAN COMPRESSION STRENGTH VERSUS CURING TIME

	30 days	60 days	90 days	1 year	20 years
A	0,57	0,60	0,80	0,79	0,75
B	0,37	0,44	0,48	0,42	0,38

In this case, lime mortar with red sand appears much stronger than the mortar casted with black sand aggregate. The full compressive strength for the hydraulic mortar specimens is achieved after ninety days and then it is maintained almost constant in time.

In this case, lime mortar with red sand appears much stronger than the mortar casted with black sand aggregate (fig.5). The full compressive strength for the hydraulic mortar specimens is achieved after ninety days and then it is maintained almost constant in time.

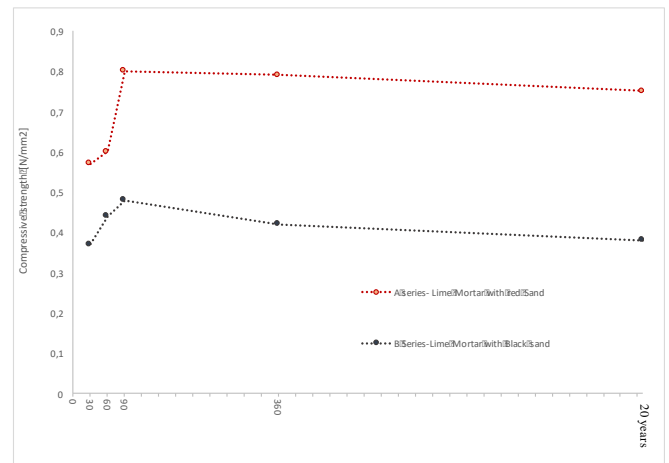


Figure 5. Compression strength vs curing time

By referring to twenty years curing, the percentage decay in respect the 1 year curing data, is equal to 6% for A series mortar and equal to 10 % for B series mortar.

D. Elastic Moduli test

Cylindrical samples 5 cm in diameter and 10 cm tall, were used for monotonic instrumented compression tests aimed to the assessment of the elastic moduli of the series specimens.

Three LVDTs displacement transducers were positioned at 120°, with a 50 mm base long as visible in figure 6. This distribution was chosen to minimize the application of the glue to the specimen, leaving the central part of the specimen undisturbed. Elastic modulus was assessed at 1/3 of the ultimate stress by referring to the stress-strain curve

Table V highlights that the mean elastic modulus is inversely proportional to the compressive strength. The time influence in this case, is not negligible, since a reduction of 20% is

recorded in the ratio between 1year/20 years of curing.

TABLE V. ELASTIC MODULUS VS CURING TIME

	30 days	60 days	90 days	1 year	20 years
A	860	1040	961.04	749.11	
B	2486	2737	1919.2	1526	

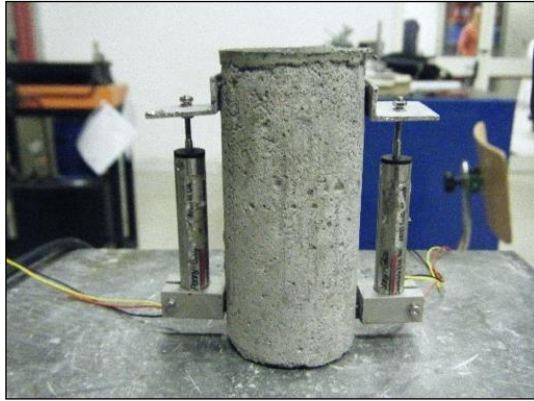


Figure 6. Instrumented Specimen for elastic modulus

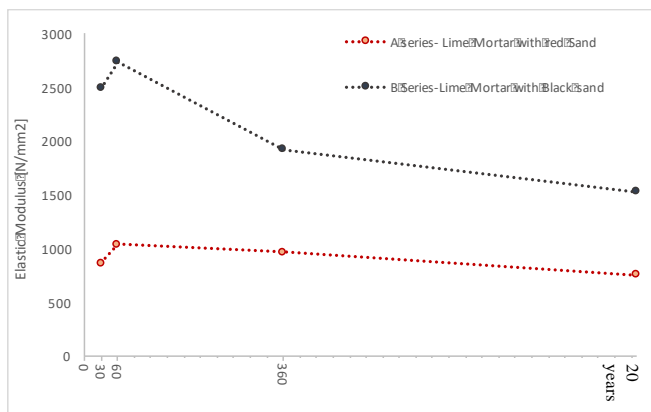


Figure 7. Elastic modulus vs curing time

IV. CONCLUSIONS

The study described in this paper, aims to identify the influence of time on the mechanical characteristics of the mortars employed in the historical buildings of Eastern Sicily. Two Lime mortars type has been identified, characterized by the use of the same binder but with different aggregates. In the lime mortar studied, curing is fast and the time does not seem to affect the final resistance. In fact, only a loss of 3-5% is recorded in terms of flexural strength. Even the compressive strength is almost constant over time.

All of these data could be useful for creating compatible mortar recipes for restoration works as well as to define technology advancement.

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