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*Characterization of lime mortars for their use in restoration of cultural heritage and in modern construction*
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# Characterization of Lime Mortars for their use in Restoration of Cultural Heritage and in Modern Construction

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## INTRODUCTION

In recent years scientific world is demonstrating a renewed interest towards the study of the properties and characteristics of ancient mortars, in order to obtain a better knowledge on the fabrication techniques and the application methods used in the past. Moreover, it is impossible to recuperate the ancient thecniques of construction because of the new requisites of the modern industry, among them time of setting and costs of production.

The aim of this research work was the study of new types of lime-based mortars, elaborated according to the requirements imposed by the modern industry of construction, especially in the choice of raw materials and the fabrication techniques. This study want to be a starting point for the design of new repair mortars that can be employed both in Cultural Heritage and in modern construction.

For this, new repair lime-based mortars of different composition were elaborated studying their chemical-mineralogical and physical-mecanical properties and their evolution along the time.

## MATERIALS and METHODS

Seven types of lime mortars have been elaborated and studied. The components of each type of mortar were: calcitic lime + calcitic aggregate (PA); calcitic lime + siliceous aggregate (P2A); dolomitic lime + calcitic aggregate (PB); dolomitic lime + siliceous aggregate (P2B); calcitic lime + white Portland cement + calcitic aggregate (PAC); calcitic lime + metakaolin + calcitic aggregate (PAM); calcitic lime + calcium sulfoalluminate + calcitic aggregate (PAS). These mortars were prepared with a binder-aggregate ratio of 1:3 by weight. In PAC, PAM and PAS mortars, additives were added replacing 25 wt.% of lime.

In order to evaluate the differences between the different types of lime mortars as well as their modifications due to the carbonation process, mortars have been studied both in their fresh and hardening state. Mortars fresh properties like consistance, workability and water shrinkage were studied. During the hardening, the internal and external zones of each samples was analyzed after 28 days, 2 and 6 months. Chemical and mineralogical composition of both original materials and mortars was analyzed by means of X-ray fluorescence (XRF, S4 PIONEER-BRUKER), X-ray diffraction (XRD, PhilipsPW-1710) and thermogravimetric analysis (TGA, Shimadzu, TGA-50H). Textural properties were observed with optical microscopy (OM, Olympus BX-60) and field emission scanning electron microscopy (FESEM, Carl Zeiss, Leo-Gemini 1530). The porosity of the mortars was investigated by mercury injection porosimetry (MIP, Micrometics Autopore III 9410) and $N_2$ adsorption (Micromeritics 3000 Tristar). Ultrasounds thecnique (Panametrics HV Pulser/Receiver 5058 PR coupled with a Tektronix TDS 3012B osciloscope) was used in order to determine the degree of compactness while mechanical tests (UNE-EN 1015-11) were carried out to measure compressive and flexural strenght to the mortars. Finally, hydric properties of mortars were characterized by means of free water absorption (UNI-EN 13755), drying (NORMAL 29-88) and capillarity tests (UNI-EN 1925).

## RESULTS and DISCUSSION.

The mineralogic study by means of XRD and TGA demonstrates that lime mortar carbonation is a very slow process that moves from the surface towards the interior of the material (*fig. 1,left*). Many crystals of portlandite are visible in mortars, even after 60 days since their elaboration (*fig. 1,right*).

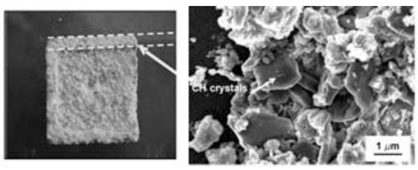


*fig 1, left. Carbonation thickness (4 mm) in PA mortar after 28 days since elaboration.fig 1, right. FESEM image: presence of portlandite crystals and amorphous calcite in PA mortars.*

MIP data demonstrate that an increase of the total porosity of mortars (fig. 2) takes place during the time and this seems to be related to the carbonation process. On the other hand, this increase is partly due to the progressive hardening of mortars that, due to the loss of the kneading water, suffer the shrinkage phenomenon that happen with the formation of small cracks, observed under optical microscopy and responsible for the increase of pore volume.

The values of real density and ultrasonic waves' velocity are concordant

**palabras clave:** Morteros, Puzolana, Metacaolín, Aluminatos, Ettringita.

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with compressive and flexural tests data. This demonstrates that there is a clear relationship between the dynamic and static mechanical properties of mortars.
The carbonation process results in a

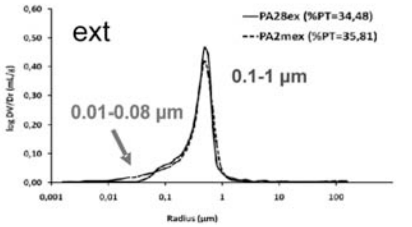


*fig 2. MIP pores size distribution curves of the external zone of PA mortars after 28 and 60 days.*

slow increase of the compactness and the mechanical resistance of mortars. However, after seven months from their elaboration, lime mortars have not still reached a good compactness and hardness, as a partial disintegration of the material demonstrates after forced water absorption test.

Hardening and carbonation processes also influence hygric properties of mortars. If, on one hand, the absorbed amount of water decreases during the time, which represents a positive factor, the capacity of mortars to dry does not seem to improve. In fact, the water is retained during more time inside mortars, a fact that makes worse their hygric qualities.

The granulometry of the aggregate (grain size and morphology), responsible of the mass mortar packing, influences the porometric distribution of the mortar and its mechanical properties. Mortars prepared with calcitic aggregate provide higher values of mechanical resistance, due to a grain size distribution of calcitic aggregate very similar to Fuller ideal curve which confers a greater compactness with respect to siliceous aggregate. Therefore, the Fuller-Bolomey theoretical curve, applied in the construction of the granulometry of calcitic aggregate to obtain the maximum resistance, is a valid model not only for concretes and cement or mixed mortars (of Portland cement + lime), but also for air lime mortars.

Mortars prepared with calcitic lime and calcitic aggregate (PA) reaches a greater carbonation and provides the highest density values, mechanical compactness and resistance. Nevertheless, among all mortars, PA absorbs the greater amount of water, by free and capillarity absorption.
Dolomitic lime mortars (PB and P2B) provide the lowest values of carbonation. Moreover, they show elevated shrinkage, little compactness and the worse mechanical behavior.

Mortars prepared with Portland cement (PAC) do not provide satisfactory results after two months from their elaboration. From mineralogic data, porosimetric analyses and mechanical tests no improvements were observed by the addition of cement replacing 25 wt.% of lime. Indeed, the use of cement improve neither the mechanical properties nor the hydric properties (fig. 3) of lime mortars.

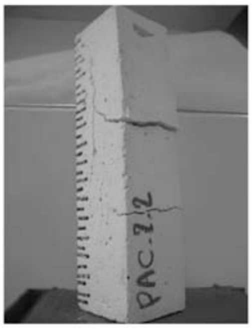

*fig 3. Fracture development in PAC mortar after the capillarity essay.*

The addition of metakaolin in mortars with calcitic lime (PAM) provokes some important changes in its physico-mechanical properties. In these mortars, a very high total porosity was measured. This demonstrates that metakaolin, knewed for "*micro-filling*" effect that shows in cement mortars, acts differently in lime mortars. On the other hand, a substantial improvement of the resistance to mechanical stresses and to hydric properties of mortars has been observed. PAM mortars absorbed the lower amount of water by capillarity and more slowly with respect to other mortars. Finally, mortars prepared with calcium sulfoalluminate (PAS) are those that, with PAM mortars, showed the best mechanical behaviors and provided the lowest shrinkage values. A negative factor due to the addition of the calcium sulfoalluminate is the presence of ettringite in mortars, which is formed in amounts of approximately 5% after two months of carbonation.


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