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Traditional methods of mortar preparation: The hot lime mix method

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ABSTRACT

This paper studies the effect of maturation on mortars prepared according to a traditional method of slaking quicklime mixed with sand and kept wet until used (hot lime mix). Two lime/aggregate weight proportions were considered, a rich one (1:5) and a normal one (1:13). The quicklime was used as pieces of crushed calcined limestone and as micronized quicklime, both from industrial production. The mortars prepared with hot lime were kept wet for periods of 1, 7, 45 and 90 days, before moulding, while those prepared with micronized quicklime were matured for 7, 45 and 90 days. After the specimens were moulded, their mechanical and water-related behaviour was studied at 28, 90 and 360 days. Mercury intrusion porosimetry and SEM observations were performed for some of the mortars to follow the microstructure changes. The aim was to understand the advantages and drawbacks of this traditional process and of a similar process with industrial quicklime. It was concluded that the maturation time has a very positive influence on flexural and compressive strength, cracking susceptibility and water absorption by capillarity. However, the process has also disadvantages, such as time consuming preparation and need of extreme care.

1. Introduction

In many countries built heritage has largely been constructed using lime techniques, as borne out by many authors [1–3]. The recent trend to replace lime with Portland cement in interventions in old buildings has been the cause of many anomalies because the latter is incompatible with old masonry [4–10]. The importance of using compatible mortars and of preserving the richness and diversity of façades has led to the need to study traditional techniques, since the knowledge of many of them is being progressively lost with the introduction of new materials.

Limes were used in construction until the 20th century, very often as lime putty. Once stone had been made into lime it was stored to prevent loss of its characteristics.

Another traditional method was to slake lime with sand (hot lime mix). Records show that the quicklime was added to sand in a pre-defined volume proportion and that the mortar was kept wet for as long as possible. It was used as the work progressed by adding enough water to give it the appropriate consistency [11–15]. This technology was used in masonry mortar, where the expansion of lime between the stones or bricks improved the bond between them and consequently produced high-strength masonry [15].

Slaking lime with wet sand was also used in render and plaster mortars. Here the mortar was only applied after 3–30 days of maturation to allow complete hydration of the hot lime. This method was still used in Alentejo (in southern Portugal) a few decades ago and the masons that used it are now few in number, but they can still be found. They say that the effect of this technique for renders and plasters was to increase strength due to better bonding of the lime and sand grains as the lime expands and heat is released by the hydration reaction.

Experiments on a medieval castle in Sweden using quicklime and wet sand mixes for renders showed higher mechanical strength and lower porosity after 1 year compared with a lime putty mortar, but there was also some crazing [14].

Advances in processes for storing materials led to change, and most of the binders used nowadays are in powder form. Slaked lime is produced in a factory and the powdery product is stored in *kraft* paper bags, with all due care being taken to prevent it from coming into contact with atmospheric carbon dioxide.

The aim of this work is to evaluate the influence of the maturation time of the mortar made of quicklime mixed with sand and kept wet for 1, 7, 45 and 90 days and determine whether there are advantages today in retrieving this method of preparation of lime mortars for restoration purposes, using crushed (in the traditional way) or micronized quicklime.

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2. Materials and testing procedures

2.1. Materials and proportions

Mortars with two different quicklime types, pieces and micronized, were tested. Two different binder/aggregate ratios were selected: the first one, richer in binder (1:5, in weight), was based on literature results from the analysis of old mortars, where rich mortars are often refereed [2,16]; the second one, less rich in lime (1:13, in weight), was chosen because the first mix showed a strong tendency to crack when applied on bricks.

When analysing the selected binder proportions it should be taken into account that the volume of calcium hydroxide obtained with quicklime is much higher (about twice) compared to the volume of calcium hydroxide obtained with hydrated lime powder, as was found in some preliminary tests where the increase in volume after hydration of the quicklime was measured.

The industrial aerial lime used (CL 90) is produced from Alcanede limestone.

Energy-dispersive X-ray fluorescence spectrometry (EDXRF) was used for multi-element analysis of the limestone and lime (Table 1). The EDXRF analyses were made on pressed pellets using the monochromatic radiation emitted by Rh X-ray tube. The powdered samples (<106 μm) were dried at 60 °C and analysed in a thermal analysis equipment (TGA-DTA) in an argon atmosphere (3 L/h). The heating rate was 10 °C/min from room temperature to 1000 °C. Thermal variations associated with the chemical and physical transformations, such as portlandite dehydroxylation (in the range 350–550 °C) and calcite decomposition (in the range 550–850 °C), were obtained by TGA-DTA analysis. From these data, the amount of portlandite and calcite was calculated (Table 1). The high value of calcite (23%) indicates that there is some carbonation of the micronized quicklime, which could have occurred during the manipulation for the tests of the very reactive product mainly on the surface.

The materials and storage time (days) used with hot lime mixes are shown in Table 2.

The lime was used in the form of pieces of calcium oxide (CaO) with a density of 873.6 kg/m^3, and as micronized quicklime with a density of 617.4 kg/m^3. The quicklime used in stone form (Q) was broken up at the factory into pieces of a more uniform diameter of approximately 5 cm. The micronized quicklime (MQ) was ground at the factory.

Small, dark grains were observed in the limestone and were analysed by X-ray diffractometry (XRD) to find out their composition (Fig. 1). The XRD diffractogram (Fig. 2) shows, apart from some quartz, the presence of an anhydrous calcium silicate (belite) and cristobalite. These two compounds could be attributed to the reaction that occurs at the high temperatures, used in industrial lime kilns (between 900 and 1100 °C), between silica and calcium compounds present in the limestone rock, according to the following reaction:

$$2CaCO_3 + SiO_2 \rightarrow 2CaO \cdot SiO_2 + 2CO_2 \quad (1)$$

A mix of two siliceous sands was used, with different grain size distributions and grain shapes (Fig. 3). The fine sand, A1, has a sub-rounded, high sphericity grain, while the coarse sand, A2, has a sub-rounded, low sphericity grain. The measured bulk densities were 1452 kg/m^3 and 1485 kg/m^3, respectively, for the fine and coarse sand.

With a sand mix (1/3 A1 + 2/3 A2) a grading curve with a balanced proportion of fine and coarse grains was obtained (Fig. 3). This was considered adequate for render since it offered adequate workability.

The sand used in the mixes was previously dried until constant weight.

The following weight proportions were used for the mortars:

- 1 binder: 5 aggregate;
- 1 binder: 13 aggregate.

The higher binder content was studied for maturation times of 1 and 7 days (mortars with pieces of quicklime) and 7 days (micronized quicklime mortar). The lower binder content mortars were studied for maturation times of 7, 45 and 90 days for the two types of quicklime (Table 3).

2.2. Mortars with pieces of quicklime

The quicklime (Q) was incorporated into the dried sand and covered with the sand on a wooden board and enough water was added gradually during 1 day to ensure the lime hydration, transforming calcium oxide into calcium hydroxide $Ca(OH)_2$ (Fig. 4). During this process the mix temperature was generally within the 40–80 °C interval but temperatures in the range of 100–170 °C were reached locally.

The receptacle under non-controlled interior environmental conditions was covered with a plastic sheet to prevent quick evaporation and the mix was kept damp by adding small quantities of water throughout the process (Table 2) to prevent carbonation.

The specimens were moulded in two stages, 1 and 7 days after the initial mixing, with a mortar type (1:5 ratio), designated QM.1-1 and QM.1-7, respectively (Table 2).

Before moulding, the mixes with 1 and 7 days maturation were put into the mixer where additional water was added and the pastes were homogenised until they gained a consistence suitable for application as render, quantified by measures on the flow table (Table 3). The second mortar type (1:13 ratio), QM.2, was prepared by slaking the quicklime mixed with sand, as described before. Enough mortar was prepared to be studied at three different maturation periods: 7, 45 and 90 days, designated as QM.2-7, QM.2-45 and QM.2-90, respectively.

2.3. Mortars with micronized quicklime

The mortars were prepared by slaking the quicklime (MQ) mixed with sand as described in §2.2. The start of the lime slaking process occurs earlier with micronized quicklime than with quicklime pieces but the temperatures reached were similar. The maturation time for mix MQM.1 was only 7 days, MQM.1-7 (Table 2). For the second mix three maturation periods, 7, 45 and 90 days, were studied, corresponding to mortars MQM.2-7, MQM.2-45 and MQM.2-90, respectively (Table 2).

Table 1
XRF chemical composition of limestone and lime (weight%, normalized to 100%) and portlandite and calcite contents obtained by ATG-DTA (weight%).

Samples	CaO	Fe_2O_3	Al_2O_3	SiO_2	MgO	SO_3	Fe_2O_3	K_2O	MnO	CuO	LOI*	$Ca(OH)_2$	$CaCO_3$
Alcanede limestone	52.3	0.1	0.7	0.4	1.5	0.2	0.1	0.8	0.06	0.06	43.78		99.5
Alcanede lime	71.9		0.1	0.2		0.2	0.03				27.57	74	23

* Determined by TGA-DTA.

Table 2
Amounts of materials and storage time (days) used with hot lime mixes.

Type of material	Density (kg/m^3)	Pieces of quicklime (Q)					Micronized quicklime (MQ)			
		QM.1		QM.2			MQM.1	MQM.2		
Weight proportions		1:5		1:13			1:5	1:13		
Volumetric proportions		1:3		1:8			1:2	1:5.5		
Storage time (days)		1	7	7	45	90	7	7	45	90
Added materials (kg)										
Quicklime Q	873.6	5.34		6.25						
Quicklime MQ	617.4						5.34	6.25		
Sand A2	1485.4	18.14		55.62			18.14	55.62		
Sand A1	1452.4	7.96		27.19			7.96	27.19		
Added water (l)										
1st day		13		15			13	15		
Other days		13		15			10	11		

Fig. 1. Darker impurities in the industrial quicklime in stone.

2.4. Characterization tests

The mortars were characterized by testing them to determine their mechanical performance, susceptibility to water and microstructure development.

The mortars were prepared in accordance with European standard EN 1015-2 [17]: 2-min mechanical mixing in a standard mixer, where water was added in the first 30 s; manual mixing of the materials; further mechanical mixing for another 30 s. For the hardened mortar tests the paste was put into prismatic moulds, 40 × 40 × 160 (mm), and circular test cups, area ≈ 0.02 m^2, were used for water vapour permeability tests.

The specimens were kept in an environment characterized by relative humidity of 50 ± 5% and temperature of 23 ± 2 °C until the end of the tests. They were demoulded at 3 days.

The methods and the number of repeated tests for mortars characterization were as follows:

- Fresh mortar:
  - Consistency of fresh mortar by flow table (3 measures) – EN 1015-3 [18];
  - Bulk density (3 measures) – EN 1015-2 [17];
- Hardened mortar:
  - Flexural and compressive strengths (28, 90 and 360 days), (3 and 6 measures, respectively) – EN 1015-11 [19];
  - Water absorption due to capillary action (28, 90 and 360 days) (3 measures) – EN 1015-18 [20];
  - Water vapour permeability (90 days), (3 measures) – EN 1015-19 [21];

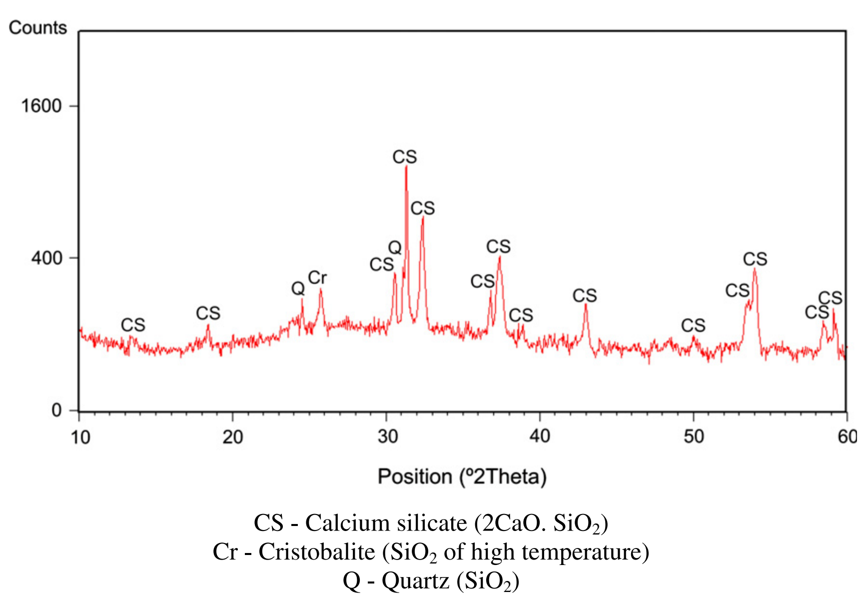

Fig. 2. Mineralogical composition determined by XRD of a darker portion of quicklime.

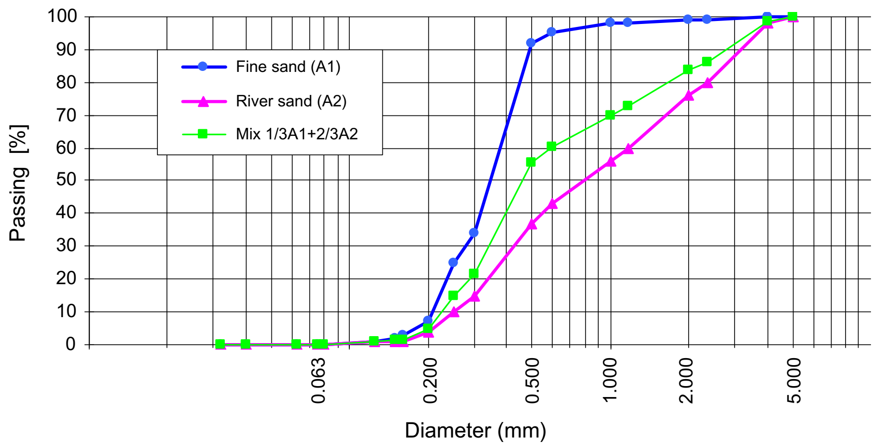

Fig. 3. Aggregate grain size distribution.

Table 3
Results of the tests on fresh mortars prepared for the study of the maturation of hot lime (pieces).

Mortar	QM.1-1	QM.1-7	QM.2-7	QM.2-45	QM.2-90	QM.1-7	MQM.2-7	MQM.2-45	MQM.2-90
Storage time (days)	**1**	**7**	**7**	**45**	**90**	**7**	**7**	**45**	**90**
Weight proportions	1:5	1:5	1:13	1:13	1:13	1:5	1:13	1:13	1:13
Added water in 3 kg of fresh mortar (ml)	250	80	250	250	250	100	250	200	150
Flow (mm)	142	148	131	130	138	130	140	140	140
Density (kg/m^3)	1863	1921	1959	1968	1972	2008	1975	1978	1965

Fig. 4. Introduction of the quicklime into the sand mix.

- Modulus of elasticity measured by resonance frequency (28, 90 and 360 days) (3 measures) – Cahier 2669-4 do CSTB [22];
- Mercury intrusion porosimetry (MIP) – ASTM [23];
- Dimensional variation due to shrinkage, measured with a vernier calliper;
- Paste microstructure by scanning electron microscopy.

3. Test results

3.1. Mortars with pieces of quicklime

During the preparation of the specimens a higher plasticity of the sand and lime mix with 7 days maturation (QM.1-7) was observed compared to the 1 day maturation one (QM.1-1), leading to a higher density; less water was needed to obtain an adequate workability for the QM.1-7 mortar to be applied and a slightly larger flow value was obtained on the flow table (Table 3).

It was found that a 7 days maturation period had a positive influence on the performance of the hardened mortar (Table 4), namely slightly higher values of mechanical strength were registered.

The mortars had a very high lime (calcium hydroxide) content (the volume approximately doubled with the hydration process) and since the carbonation process is slow the strength obtained in the first few days was low and increased with time, as reported by other researchers [14]. The high binder content led to high shrinkage and consequent micro-cracking of the mortars (Fig. 5). This may have prevented better results for mechanical strength. Due to the extension of maturation time from 1 to 7 days, increases of flexural strength and compressive strength were registered.

The maturation of the QM.2 mixes had a positive effect on the workability of the mortar, as seen in the variation of the results from 7 to 90 days, for QM.2-7 and QM.2-90 (Table 3). For the same values of added water the mortar consistency determined by the flow table became slightly higher as the maturation proceeded. According to some authors [24–28], the better workability with longer maturation time seems to be strongly related to the change of morphology and size of the portlandite crystals, which decrease in size and change shape.

The results in Table 4 show a trend of improvement in terms of mechanical and water-related performance. Mechanical properties are positively affected by maturation. The increase in compressive strength at 360 days was around 31% and for flexural strength it was around 33%. The values of the modulus of elasticity follow the trend of increase with maturation time, though at moderate levels.

Lengthening the period during which the mix was kept wet also had a positive effect on water absorption by capillarity in QM.2 hot lime mixes. This occurred more slowly in mortars with higher maturation times and translated into smaller capillarity coefficients. Total open porosity fell with increasing maturation time. The water vapour permeability values increased from 7 to 45 days of maturation time and remained the same until 90 days maturation.

Table 4
Results (average values) of the tests on hardened mortars prepared for the study of the maturation of hot lime (pieces).

Mortar	QM.1-1	QM.1-7	QM.2-7	QM.2-45	QM.2-90	MQM.1-7	MQM.2-7	MQM.2-45	MQM.2-90
Modulus of elasticity (MPa) 28 days	2879 (89)	4388 (258)	3041 (57)	3260 (91)	3505 (64)	2971 (167)	3465 (68)	2911 (101)	3080 (29)
Modulus of elasticity (MPa) 90 days	3816 (306)	3658 (306)	3305 (30)	3478 (137)	3999 (114)	4595 (52)	3381 (88)	3317 (27)	3418 (18)
Modulus of elasticity (MPa) 360 days	**n.d.**	**n.d.**	**3486** (299)	**3763** (27)	**4027** (109)	**4973** (124)	**4265** (123)	**4462** (30)	**3440** (41)
Flexural strength (MPa) 28 days	0.30 (0.00)	0.43 (0.08)	0.40 (0.05)	0.48 (0.12)	0.50 (0.00)	0.42 (0.08)	0.43 (0.03)	0.23 (0.03)	0.43 (0.08)
Flexural strength (MPa) 90 days	0.47 (0.06)	0.50 (0.15)	0.70 (0.00)	0.60 (0.05)	0.65 (0.05)	0.47 (0,10)	0.43 (0.03)	0.32 (0.13)	0.47 (0.03)
Flexural strength (MPa) 360 days	**n.d.**	**n.d.**	**0.45** (0.00)	**0.53** (0.08)	**0.60** (0.00)	**0.52** (0.14)	**0.47** (0.08)	**0.58** (0.10)	**0.43** (0.06)
Compressive strength (MPa) 28 days	0.57 (0.04)	0.60 (0.07)	0.64 (0.04)	0.88 (0.10)	1.12 (0.07)	0.81 (0.09)	0.85 (0.04)	0.63 (0.08)	0.63 (0.11)
Compressive strength (MPa) 90 days	0.96 (0.05)	1.08 (0.08)	1.03 (0.09)	1.11 (0.05)	1.36 (0.10)	1.18 (0.16)	0.83 (0.04)	0.88 (0.06)	0.99 (0.04)
Compressive strength (MPa) at 360 days	**n.d.**	**n.d.**	**0.86** (0.07)	**0.96** (0.04)	**1.13** (0.04)	**1.63** (0.11)	**0.86** (0.07)	**1.14** (0.07)	**1.05** (0.06)
Capillarity coefficient (kg/m^2 min½) at 28 days	1.11* (0.03)	1.33 (0.05)	2.30* (0.09)	2.09* (0.03)	1.84* (0.14)	1.26 (0.08)	1.78 (0.03)	1.53 (0.02)	1.65 (0.06)
Capillarity coefficient (kg/m^2 min½) at 90 days	1.65 (0.05)	1.48 (0.03)	2.70* (0.26)	1.89* (0.06)	1.90* (0.15)	1.40 (0.06)	1.78 (0.09)	1.41 (0.06)	1.42 (0.05)
Capillarity coefficient (kg/m^2 min½) at 360 days	**n.d.**	**n.d.**	**1.92** (0.16)	**2.00** (0.07)	**1.56** (0.05)	**1.37** (0.02)	**1.60** (0.10)	**1.20** (0.04)	**1.39** (0.06)
Water vapour permeability (ng/m.s Pa) at 90 days	**23.38** (1.08)	**22.54** (n.d.)	**26.81** (1.06)	**30.86** (0.155)	**30.97** (1.70)	**21.43** (0.51)	**33.02** (4.52)	**26.28** (0.51)	**29.07** (1.92)

n.d. Not determined.
() standard deviation.
* Test performed according to EN 1015-18 but simplified by using full prismatic specimens 40 × 40 × 160 mm without lateral sealing.

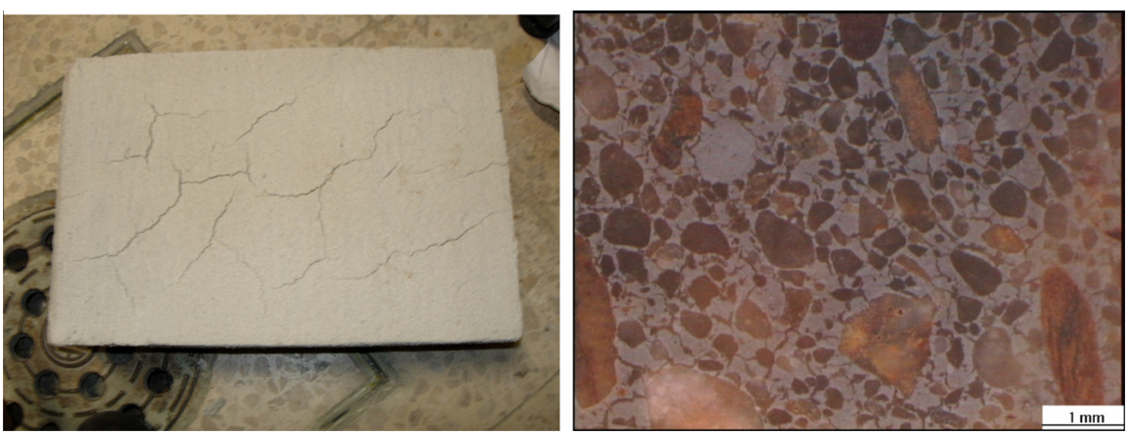

Fig. 5. Mortar prepared with quicklime pieces, QM.1-7 (7-day maturation).

The temperatures reached during the transformation of calcium oxide into calcium hydroxide allow an increase in the kinetics of the pozzolanic reaction between the quicklime (Q) and the reactive/altered minerals in the sands. The presence of a calcium aluminosilicate was noted by SEM/EDS in these mortars (Fig. 6).

3.2. Mortars with micronized quicklime

These mortars with micronized quicklime (MQM) were characterized in order to be compared with mortars prepared with pieces of quicklime (QM), using the same test methods.

The tests carried out with pieces of quicklime revealed that the mortars prepared using this traditional method should not be used 1 day after mixing the constituents since this was too short a period for proper extinction of the calcium oxide, so test specimens were only prepared using micronized quicklime having matured for 7 days (Table 2).

Better plasticity for the MQM.2 mixes was obtained with maturation time as also found by other authors with lime putty [25,29]. The flow test results were the same with addition of less water (Table 3).

Maturation time did not have a positive linear influence on mechanical behaviour. Some results obtained after 90 days maturation were lower than the results obtained after 7 days (Table 3).

For the mixes with higher lime content, MQM.1-7, the results for hardened mortars showed almost twice the compressive strength from 28 to 360 days. These results agree with those of other authors [14,29–33] and an increment for modulus of elasticity and flexural strength (Table 4). Lanas et al. [31] concluded that the mechanical performance of mortars in terms of compressive and flexural strength has a considerable increase between 26 and 360 days, the more so for high binder/aggregate ratios (1:1, 1:2), by volume [30,31]. Values from those researchers at 360 days varied from 1 MPa to 5 MPa. In our study using the hot lime technology the compressive strength values at 360 days varied between 1.05 MPa and 1.63 MPa. Beck and Al-Mukhtar [32] studied various lime mortar mixes and concluded that the mechanical properties improved with the lime content [32]. Faria et al. [29] studied a mix with a binder: aggregate ratio (1:2) by volume, using dry hydrated lime and putty, and obtained compressive strengths at 90 days from 0.35 MPa and 1.09 MPa and concluded there was an increase with maturation time. These values are generally lower

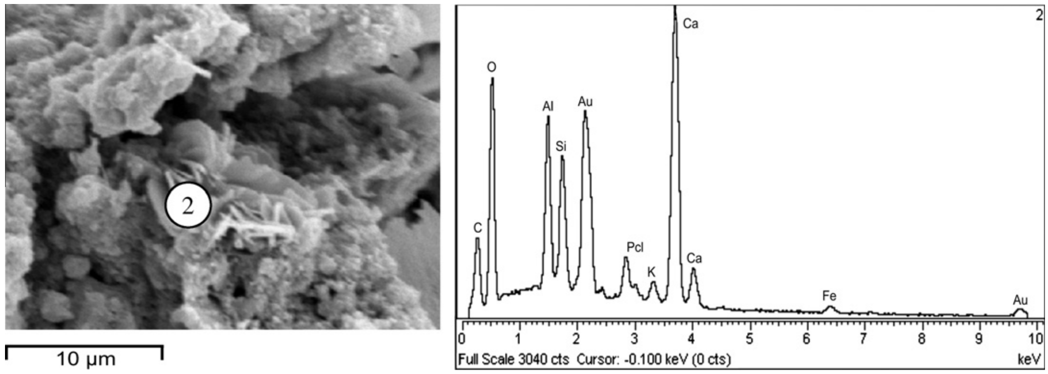

Fig. 6. SEM observations of QM.2-90 mortar and corresponding EDS showing the presence of flaky hydraulic compounds.

than those obtained using hot lime technology with pieces of quicklime. El Turki et al. [33] determined the 28-day and 56-day compressive strength of lime specimens (CL90) with a binder: sand: water ratio of 1:2:0.78 by volume and obtained values close to 0.9 MPa and 1.0 MPa, respectively [33]. In our study similar values were obtained at 28 days for the mixes richer in lime content (MQM.1-7), those with higher maturation time (QM.2-45, QM.2-90), and those with micronized quicklime (MQM.2-7).

Experience tells that mortars with higher binder content are more liable to crack, so, while their use in works may be possible or even advisable, greater care must be taken to fill in all the visible cracks by pressing the render. For mixes with lower lime content, MQM.2, the improvement in mechanical behaviour was more visible in mortars after 45 days maturation. The fact that micronized quicklime has a very fine grain size and can easily carbonate may be one of the reasons for the results found because, although the paste remained damp, some diffusion of the carbon dioxide could still occur. In this case, the quicklime stops functioning as an active binding element and functions instead as an aggregate.

The behaviour of water absorption by capillarity was not linear with maturation time. However the results obtained after 90 days of maturation were in all the samples lower than those after 7 days.

The water vapour permeability values increased with higher maturation times.

4. Discussion

The presence of silica and phyllosilicate minerals in the limestone rock could originate during the calcination the formation of under-burned and over-burned lime fragments. These fragments are often found in industrial limes sold as stone. The current use of high temperatures (above 900 °C) in industrial kilns is one of the main causes of the over-burnt elements in the lime. This is why some authors [34] argue that the use of these temperatures in industrial kilns is one of the main reasons for the resulting product being poorer in quality than ancient limes made in traditional kilns at lower temperatures. However, other authors [35] believe that industrial lime may be better than that from traditional kilns, due to more homogeneous kiln temperature during the calcination. Nonetheless, they note that the appropriate technique must be adopted, especially in terms of the temperature used. During the manufacturing, extinction and packing of micronized quicklime elements (dark patches) arising from insufficient baking or higher temperatures are eliminated.

The results obtained at 90 days for flexural strength (0.32–0.70 MPa) and compressive strength (0.83–1.36 MPa) are within the boundaries normally expected for aerial lime mortars [36].

When the mortars prepared with hot lime technology (pieces and micronized) are compared, it is found that the mechanical performance of the pieces of quicklime mortar is generally better than micronized quicklime. Pieces of quicklime are generally considered to be more active than micronized quicklime, meaning that they create stronger bonds with the aggregate, which results in greater mechanical strength. However, in the SEM observations the mortars prepared with pieces of quicklime show a more porous microstructure. The irregular size of hot lime pieces in comparison with micronized quicklime has repercussions on the dimensional variation of the mortars due to shrinkage, and these are greater in mortars prepared with hot lime pieces than in those prepared with micronized quicklime (Fig. 7). When the mortar has higher binder content there are greater similarities between the mechanical and water-related behaviour of the two types of hot lime mortars.

Water absorption by capillarity is generically greater in the mortars prepared with pieces of quicklime, although the results are closer after a maturation period of 90 days, and this may be associated with the microstructure of the paste (Fig. 8). The porosity measurements by mercury intrusion porosimetry (MIP) showed pastes with pore radius ranging from 0.01 to 1 μm, as is usual in air lime mortars [37]. Some correlations were found between porosity and capillarity (Table 5). In mortars QM.2-7 and QM.2-90 total porosity measured by MIP and total open porosity by capillarity decreased due to maturation, and this was accompanied by a decrease in the coefficients of water absorption by capillarity. The decrease in the medium pore radius with maturation time (Fig. 8) helps to explain the lower capillarity coefficient of QM.2-90. In micronized quicklime mortar the maturation period had no visible effect on total open porosity measured by MIP, but there was a decrease in the capillarity coefficients due to maturation, probably due to a small increase in proportion of larger pores, as can be seen in Fig. 8. A change in porous microstructure under the effect of maturation is more evident in the process of hot lime mortar (pieces). Comparing the pore radius distribution of the hot lime mortars (pieces) QM.2-7 and QM.2-90, the peaks of particles with an identical size are higher than when micronized quicklime is used, as in MQM.2-7 and MQM.2-90. The pore radius distribution is very close in the mortars prepared with micronized quicklime, with distinct maturation periods.

The presence of very porous sizeable lumps that remained in the mortar explains the results for the water-related performance of the mortars prepared with quicklime (QM), which show higher capillary coefficients than micronized quicklime mortars (MQM). In fact, SEM observations show a perceptible difference in the microstructure of the mortars prepared with quicklime in comparison with those prepared with micronized quicklime. The hot lime mortars (pieces) have microstructures which are more porous and have more empty spaces (Fig. 9).

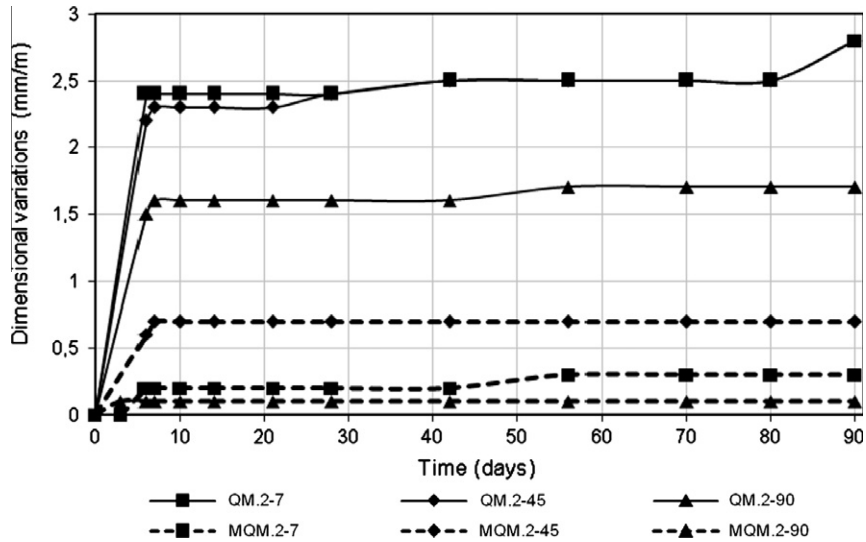

Fig. 7. Comparison of the dimensional variation, of mortars prepared with quicklime:sand weight ratios of 1:5 and 1:13.

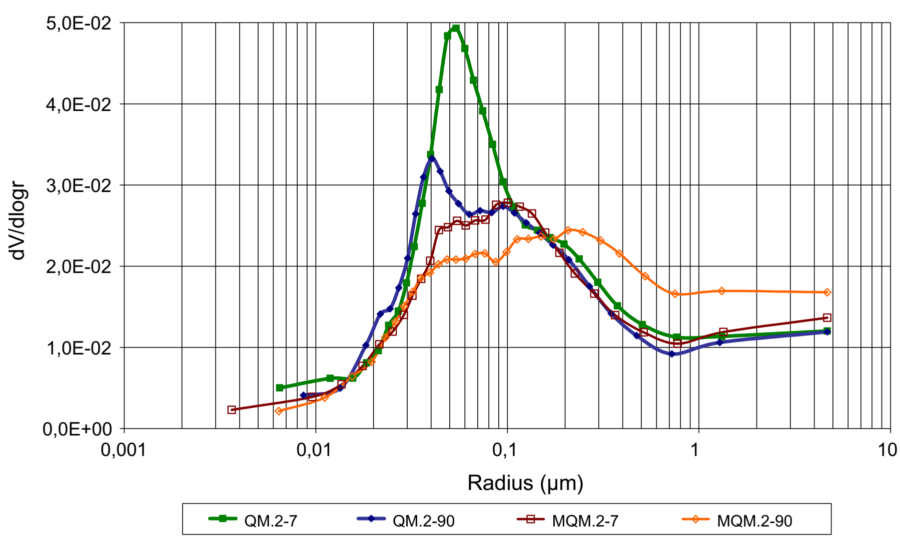

Fig. 8. Comparison of the pore radius distribution of mortars prepared with quicklime (pieces and micronized) at different maturation times.

Table 5
Comparison of porosimetry (from 0.002 to 4.68 µm) and total porosity of mortars prepared with quicklime (pieces and micronized) with different maturation time.

Quicklime	Pieces (Q)		Micronized (MQ)	
	QM.2-7	QM.2-90	MQM.2-7	MQM.2-90
Weight mix	**1:13**			
Porosimetry from 0.002 to 4.68 µm (%)	**11.7**	**10.3**	**10.2**	**11.1**
Total open porosity (%)	**32.3 ± 0.1**	**30.9 ± 0.1**	**31.1 ± 0.1**	**31.6 ± 0.1**

The tests did reveal some disadvantages in this mortar preparation process. It is difficult to prevent lumps (over or under-burning) of quicklime (Q) from remaining in the mix, some of which are poorly hydrated lime. These nodules were detected in mortars used on bricks, even after a reasonable maturation period (7 days). The expansion process of hydration and consequent slaking of the lime caused the cracking and degradation of some of the specimens prepared with mortar QM.2-1. The mortars moulded after 45 and 90 days of maturation, QM.2-2 and QM.2-3, no longer showed any damage associated with the expansion of the quicklime (Q) during the slaking process. However, such maturation times seem too long to be used in real works nowadays.

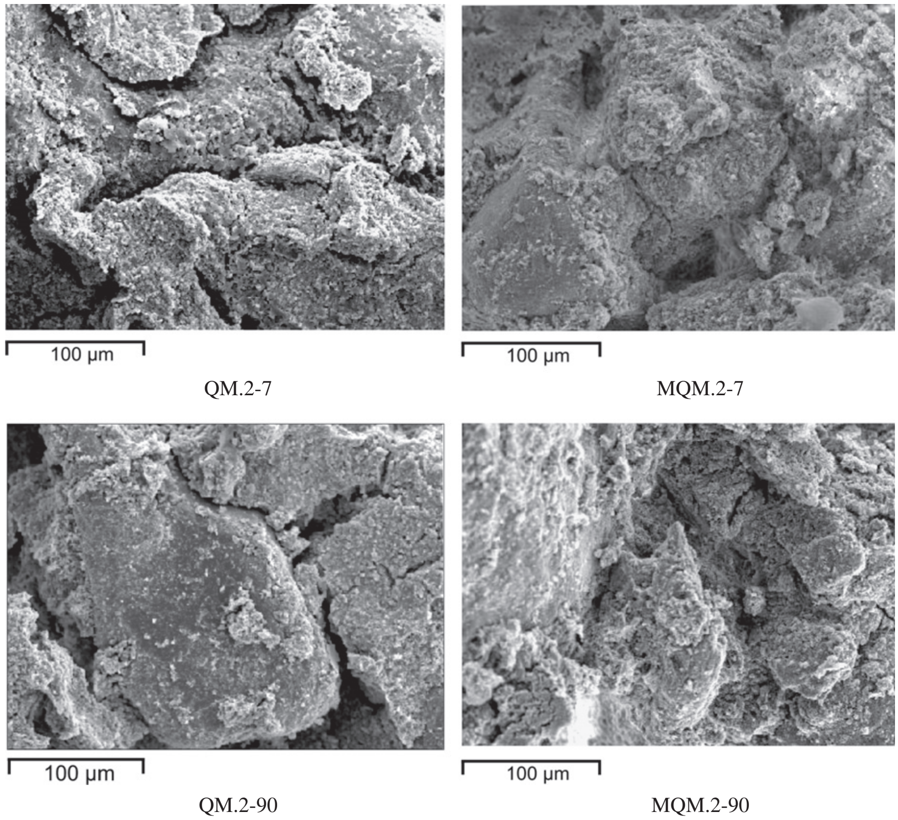

Fig. 9. SEM observations of quicklime mortars (pieces and micronized) at different maturation times.

5. Conclusion

Hot lime mixed with sand is a traditional way of making mortars, an advantage of which is the prior preparation of the lime and sand mix with water and the making of the fresh mortar to be used as the works continue. The slaking of pieces of quicklime by mixing with sand while keeping the paste wet seems to have been common practice to prevent the lime from losing its qualities over time.

The results obtained showed that the mix properties improved with the maturation time of the pastes. An improvement was observed in the paste plasticity so that less water needs to be added during the preparation of the mortars, which results in a material with better characteristics. A positive influence on the mechanical and water-related performance of mortars was noted. This influence is more evident in mortars prepared with pieces of quicklime, which generally develop higher flexural and compressive strengths than the micronized quicklime mortars, but also need longer maturation periods.

The analysis of the results shows very high capillary coefficients that are believed to be associated with the size of the quicklime pieces used, because they suggest that some lumps remain in the mortar, and these are very porous and can easily absorb water.

One of the advantages of slaking quicklime (in pieces) with sand is that this process provides a binder with higher percentage of active lime. However it must ensure that slaking is completed and prevents impurities from blending with the lime. Micronized lime can carbonate very easily so it is possible that some lime as binder does not work.

The compositions which are not as rich in binder produce mortars with greater open porosity and larger pores, which worsens their mechanical and water-related behaviour; in the mortars richer in binder an increase in strength develops at more advanced ages. However, they need special care is to avoid cracking.

The size distribution of the quicklime pieces also has repercussions on the dimensional variation of the mortars, which were higher in the mortars with pieces of quicklime than in those prepared with micronized quicklime.

Experimental results showed no particular advantage in using micronized quicklime in the traditional process of preparing hot lime mortar. They also showed that the hot lime process can lead to rather high mechanical strengths but it needs long preparation time and expertise in the application.

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