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CEMENT-LIME MORTARS JOINING POROUS STONES OF MASONRIES ABLE TO STOP THE CAPILLARY RISE OF WATER

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ABSTRACT

The capillary rise of water in porous stones of masonries can be stopped by interleaving appropriate cement-lime mortars between the building stones. The type of cement in the mortar influences the time requested for the formation of an impermeable lime layer, responsible of the phenomena.

Introduction

The decay of porous stones of masonries is frequently observed on ancient monument. Among the weathering factors, the water movement inside the porous material represents one of the main causes of alteration (1). Such a movement involves wetting and drying cycles with corresponding, not negligible, expansion and shrinkage phenomena that may lead to mechanical stresses. The presence of soluble salts in the moving water causes corresponding salts dissolution-crystallization cycles in the masonry that produce additional mechanical stresses with consequent stones deterioration (2,3).

The presence of water at the base of a masonry, responsible for the capillary rise, can be due to the rain or to the contact with water-bearing stratum. In this case, a vertical transport of water along the wall takes place. It involves a deterioration of a more or less wide band of the masonry located at a certain level respect to the ground (1).

Such a phenomenon represents a serious and hardly solved problem. Recently, cement-lime mortars joining tuff stones, volcanic and porous rocks of central-southern Italy, employed as building stones since ancient times (4,5), have been proved to form an impermeable layer of lime at tuff-mortar interface, able to stop the capillary rise of water (6). Therefore a research has been undertaken to study the role of both the content and the type of cement utilized in cement-lime mortars on the stopping the above mentioned phenomena.

Experimental

The tests were performed by using three different cements complying with the CEN UNI ENV 197-1 Standard, namely a Portland cement type I 32.5, a pozzolanic cement type IV/B 32.5 and a Portland blastfurnace cement type III/A 32.5. The cements were blended with hydrated lime at variable weight percentage ranging between 0 to 100%. The standard water/(lime+cement) ratio (7) was changed to have mortars with the same workability.

Different materials currently employed in building, have been tested: four types of tufaceous stones characterized by pozzolanic activity (8,9), one clay brick and two sandstones based on quartzite and calcite, respectively. Some of the characteristics of such stones are reported in Table 1. The nature and content of their crystalline phases were detected by X-ray diffraction (XRD) analysis and the "Capillary Absorption coefficient" (CA) was determined according to a method reported in a previous paper (10). In each experiment two cube-shaped blocks (50mm in side) of a same material were wetted and joined with the mortars (15 mm in width). The sandwiches were cured at 21°C over 90% R.H. for 14 days. Then, the lower surface of one block was set in contact with water in a tank in which the 10mm water level was kept constant by flowing water. The contact with water determines a fast water absorption by capillary uptake involving, in many cases, the overall sandwich.

The variation (Δm) with the time of the mass of the sandwich is expressed by:

$$\Delta m = \frac{m - m_{dry}}{m_{sat} - m_{dry}} \times 100$$

where: m, m_{dry} and m_{sat} are the current, dry and saturated sample masses, respectively.

The water uptake is opposed by water evaporation and the progress in the mortar hydration. Thus the form of the curve is the result of the three processes.

Results and Discussion

Effect of Cement Type. Soaking-drying curves of YTC tufaceous stones joined with mortars containing a cement (30wt%)-lime (70wt%) binder are reported in figure 1. The initial mass increase is due to the soaking of all the sandwich, while the subsequent and nearly constant mass indicates a balance between water uptake from capillary rise and water loss from evaporation.

TABLE 1
Some Characteristics of the Examined Building Materials

Sample	Typology	Main mineral phases (P=phillipsite; C=chabazite; S=sanidine; Q=quartz; CL=calcite) and their relative amounts*					CA coeff.
		P	C	S	Q	CL	
GTC	unzeolitized tuff	-	(t)	+++	-	-	0.20
YTC	zeolitized tuff	+++	(t)	(t)	-	-	0.23
YTR	zeolitized tuff	++	+	(t)	-	-	0.48
YTS	zeolitized tuff	++	+	(t)	-	-	0.60
CB	clay brick	-	-	+	+	-	0.37
QAR	quartzarenite	-	-	-	++++	-	0.01
CAR	calcarenite	-	-	-	-	++++	0.11

*The amounts were estimated from X-ray peak intensities: very strong (++++); strong (+++); medium (++); weak (+); traces (t).

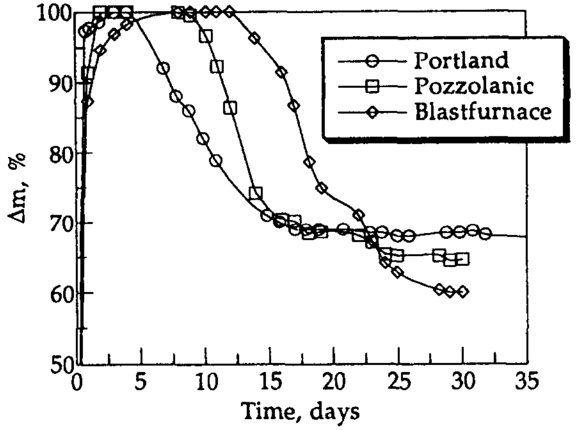

FIG. 1.
Soaking-drying curves relative to YTC tufaceous stone. Binders contain 30wt% of Portland, Pozzolanic and Blastfurnace cement, respectively.

This second stage is followed from a third one when hardening of mortar gives place to a more or less impermeable layer at tuff-mortar interface which stops or slows the capillary rise of water. If drying prevails, Δm attains a stationary value depending on the porosity and CA coefficient of the lower block.

The type of cement in lime-cement mortar has a noticeable influence on the required time to stop the capillary rise of water. Portland cement appears more efficient in comparison to mortars made with pozzolanic or blastfurnace cements (fig.1). In fact, lower soaking times are requested for mortars containing Portland cement, in respect to those of mortars made with blended cements. An analogous effect has been also verified for the other building stones listed in Table 1. Such behaviour can be explained taking into account the mechanism of formation of the impermeable lime layer at stone-mortar interface. It arises from variation of composition at the interface as a consequence of the rising water (fig. 2). The interaction between lime of mortar and alkalies contained in the tuff (K_2O and Na_2O in particular) (11), gives rise to a local increase of the pH value at tuff-mortar interface (12), which causes a lime precipitation on it from the solution in contact with the mortar. In such way, a gradient in calcium concentration forms between the interface and the bulk mortar which promotes a continuous flow of calcium, from the bulk of mortar to the interface, where it precipitates as $Ca(OH)_2$. Such impermeable

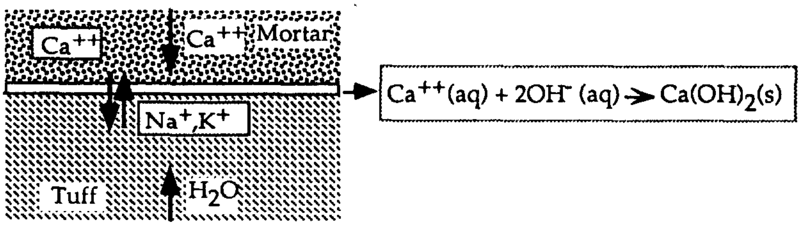

FIG. 2.
Mechanism of formation of the impermeable layer at the tuff-mortar boundary.

layer, whose composition was determined by EDS microanalysis, is shown in SEM micrographs of figure 3.

The lower soaking time of mortar manufactured with Portland cement, may be attributed to the relatively high calcium concentration of the solution in contact with such mortar respect to that of mortars made with blended cements such as pozzolanic and Portland blastfurnace cement. The consequent higher gradient in calcium concentration together with higher compactness of mortar made with Portland cement, determines a faster formation of lime layer responsible of the blocking of capillary rise. The mortars made with blended cements show, in fact, higher soaking times (fig. 1).

<u>Effect of Cement Content in the Mortars.</u> Adopting a same type of both block stone and cement in the mortar, increasing soaking times are requested for joining mortars containing increasing

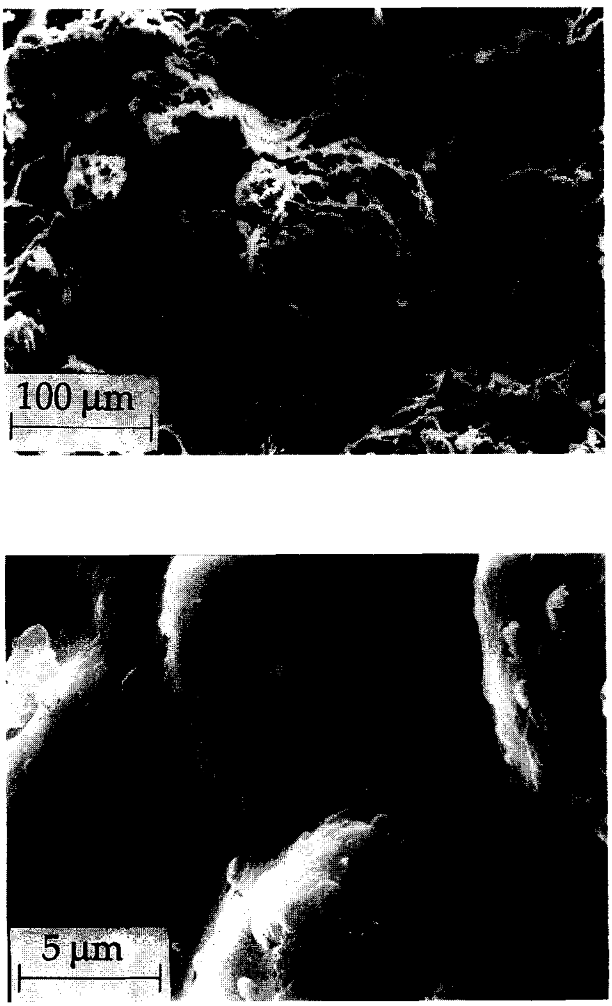

FIG. 3.
SEM micrographs of a same tuff/mortar interface showing a compact lime layer able to stop the capillary rise of water.

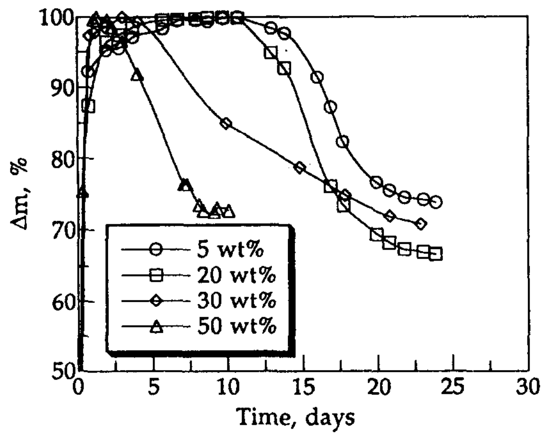

FIG. 4.
Effect of Portland cement content (wt%) in the mortars on the soaking times of YTC stones.

percentages of lime in the binder part (fig. 4). High cement content of mortar reduces, in fact, the soaking time as a consequence of higher compactness of the corresponding mortars, as outlined in Table 2, in which apparent porosity of mortars containing different amounts of lime and Portland or Pozzolanic cement is reported. In this case, in fact, the CA coefficient of mortars play an important role on the time necessary to the development of the impermeable layer. When both stone and mortar are characterized by a high CA value, the concentration gradients at stone-mortar interface are hindered by the fast water rising and inasmuch as more precipitating lime is necessary to block the higher porosity. As it can be seen in figure 5, the CA values for mortars made with different type of cement decrease by increasing the cement content in the binder part of mortar. Such behaviour agrees with the higher ability of such joined mortars to block the capillary rise.

The simultaneous effects of both the type of cement and the composition of lime-cement mortar in terms of percent of cement in the binder part of mortar are exemplified in figure 6. The Portland cement appears more effective to block the capillary rise of water, in addition the soaking times decrease by increasing the cement content in the mortar.

Effect of Nature of Building Stone. The nature of building stone also plays a fundamental role on the stopping of rising dump. Two requirements are necessary for building stones to stop the mentioned phenomenon. The first condition is represented by the capacity of stone to release

TABLE 2
Apparent Porosity* (A.P.%) of Lime/Cement Mortars Cured for 14 Days and Containing Different Types and Percentages of Cement

Cement type	wt% of cement in the blends				
	10	30	50	70	100
Portland	**29.1**	**27.7**	**27.3**	**24.9**	**22.6**
Pozzolanic	**29.5**	**29.5**	**27.1**	**25.7**	**25.3**

*Apparent porosities were measured according to RILEM recommendation, vol.13, N.75

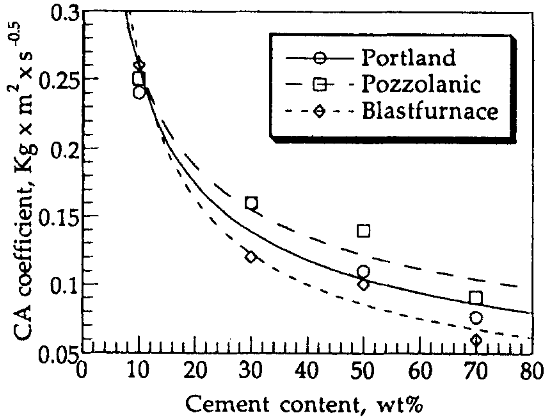

FIG. 5.
Effect of cement content in the lime-cement blends on the CA coefficient of mortars.

alkalies by interaction with lime-cement mortar. Another condition is related to the CA coefficient value of the stone. Tufaceous and zeolitized stones (YTC, YTR and YTS samples) are in fact rich in zeolite minerals whose cation exchange capacity is well known (13) and the consequent release of alkalies can be easily explained. Also unzeolitized tuff (GTC) and clay brick (CB) are able to release alkalies by interaction with lime of mortars; both stones contain, in fact, a glass phase rich in alkalies. When such an interaction takes place a low CA coefficient value of the stone kinetically favours the formation of impermeable lime layer. In this case, in fact, it is favoured the indispensable Ca^{2+} concentration gradient for a right arrangement of the precipitating lime at the impervious stone-mortar interface. Soaking-drying curves relative to the tufaceous stones are reported in figure 7; the differences in the soaking times can be related either to the kinetic of interaction or to the differences in CA coefficient of the stones (Table 1). Longer soaking times are necessary to the development of the impermeable layer when the tuffs

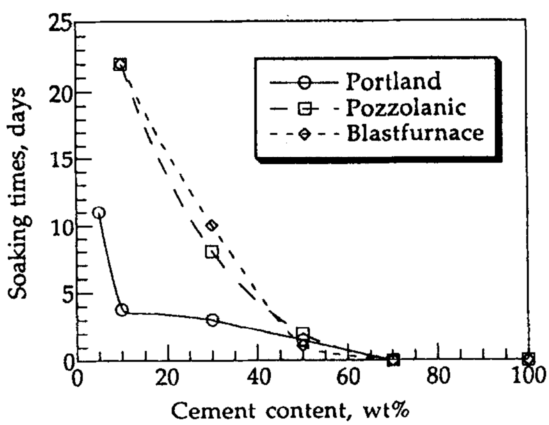

FIG. 6
Effect of both cement type and cement content in the mortars on the soaking times of the YTC stone.

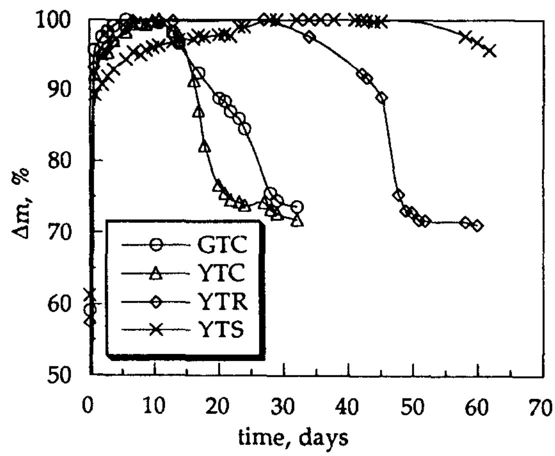

FIG. 7.
Soaking-drying curves relative to tufaceous stones listed in Table 1; binder made up by 5% Portland cement was utilized.

are characterized by higher CA values while the difference between GTC and YTC, both having low and comparable CA coefficients, must be ascribed to a different kinetic of alkalies release between the glass phases of unzeolitized GTC tuff respect to that of the zeolitized YTC tuff. In spite of the low CA values of quartzarenite (QAR) and calcarenite (CAR), the formation of the interfacial and impermeable layer is, in this case, hindered. After one year of water soaking, in fact, no layer was observed (fig. 8). Such behaviour agrees with the fact that such building stones are free of alkalies. On the contrary, the soaking tests performed using a clay brick stone determined the formation of the impermeable layer (fig. 8), thus confirming that the alkalies release at mortar-stone interface represents a necessary condition in the stopping of rising dump.

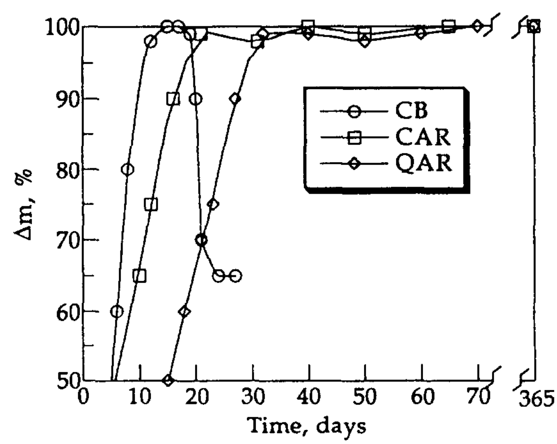

FIG. 8.
Soaking-drying curves relative to building stones listed in Table 1; a binder made up by Portland cement (50 wt%) was utilized.

Conclusions

The water soaking of porous stones joined by lime-cement mortars determines an interaction between stone and mortar able to block the capillary rise of water. Such phenomenon takes place for stones able to release alkalies by interaction with mortar. Owing such interaction, an impermeable layer of precipitating lime forms at the stone-mortar interface.

The formation of such layer is kinetically favoured by adopting mortars containing Portland cement in respect to those containing a blended cement. Low values of capillary absorption coefficient of both stones and joined mortars also reduce the soaking times requested for lime layer formation. The value of such coefficient can be reduced by increasing the cement content of mortars. In such case, however, it is difficult to assure a suitable interfacial matching between very porous stones such as tufaceous materials and less porous mortars rich in cement. The water movement at stone-mortar interface determines, in this case, a not negligible differential expansion or shrinkage that lead to mechanical stresses with consequent interfacial fracture.

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