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The effect of various slaked limes on the microstructure of a lime–cement–sand mortar

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Abstract

The present work aims to provide a better understanding of the effect of both the proportions and the characteristics of slaked lime on the microstructure of a lime–cement–sand mortar. Cement (CPA CEM I 52.5) has been replaced by various categories of slaked lime chosen for the diversity of their physico-chemical characteristics.

Cement has been replaced by lime in proportions varying between 0 to 10% of the total binder mass. With very few exceptions, mortars were produced by maintaining the quantity of water constant.

Experimental results show that it is necessary to have a high lime substitution percentage to influence the microstructure of the mortar, except in the case of a lime containing magnesium hydroxide or calcic lime featuring sizeable specific surface area.

The influence of the nature of the substituted lime on the development of the microstructure in the matrix has been examined by SEM observations of the mortar micro porosity.

Keywords: Slaked lime; Physico-chemical characteristics; Elastic modulus; Microstructure; SEM

1. Introduction

Over the past twenty years, many studies have been conducted on improving the physical and mechanical characteristics of mortars by means of adding or substituting mineral fines [1–9]. The underlying purpose of these efforts has been the protection of the environment and the conservation of energy resources, while improving mortar performance.

Even though the relationships between the microstructure and the physical properties of these new mortars have been widely discussed in these studies, it should still be noted that slaked lime has not been used often as a mineral fine.

Until now, very few scientific papers have dealt with mortars made from a mixture of slaked lime and Portland cement. Nevertheless, the research conducted by Sriboonlue and Wallo [10] merits special attention. Their work focused on the influence of the various components of a lime–cement mortar on both the mortar's mechanical strength and elastic modulus. Within the scope of their study, lime mix proportions were varied during mortar production. Philippi et al. [11] concentrated their study on the lime mortar microstructure with the aim of developing methods to analyse the microstructure of porous materials displaying a wide range of pore sizes. Upon completion of this work, Philippi proposed a three-dimensional model to represent the heterogeneous pore structure of the mortar and went on to study both water retention and humidity transfer using this model [12]. In 1996, Colantuono et al. [13] examined the capillarity phenomenon occurring in porous materials bound by lime–cement mortars. However in none of these studies was the influence of lime on the physical and chemical properties of a lime–cement mortar actually investigated.

Lime–cement mortars have started inciting renewed interest thanks to the prospect of a sizeable market for maintaining and restoring historical buildings. In light of this new development, the study of the influence of the physico-chemical characteristics

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of lime on the evolution of lime–cement–sand mortar microstructure has been undertaken.

To target these objectives, the present work has primarily focused on a Portland cement mortar in which a portion of the cement has been replaced by lime. Mortars were produced according to one of two processes: either holding the quantity of water constant or holding the level of workability constant. In order to better determine the impact of replacing cement by lime on the development of species normally present in mortars, the chemical nature of the substituted lime has also varied.

2. Experimental

2.1. Raw materials

2.1.1. Slaked limes (Ci)

The slaked limes used in this work are those which were studied by Sébaïbi Y. et al. [14]. The main characteristics of the various limes are outlined below, and presented in Table 1.

The calcium and magnesium hydroxides used herein are pure hydroxides (i.e. of analysis-grade quality); their purities are greater than 98% and 95%, respectively. On a scanning electron micrograph, both $Ca(OH)_2$ and $Mg(OH)_2$ appear as a cluster of fine platelets measuring up to 10 μm in the case of calcium hydroxide, yet whose entanglement makes it impossible to define the exact shape [15].

The industrial limes studied herein (C_1, C_2 and C_3) are slaked limes chosen for the diversity of their physico-chemical characteristics.

Table 1
Physico-chemical characteristics of the various limes tested

Samples	$Ca(OH)_2$	$Mg(OH)_2$	C_1	C_2	C_3	C_4 [a]
CaO (total)	74.2	0.1	73.5	73.9	42.3	42.1
MgO	0.7	68.2	0.4	0.6	29.8	31.5
Fe_2O_3	0.06	<0.01	0.1	0.3	0.1	0.03
SiO_2	0.10	0.08	0.8	0.3	0.4	0.09
Al_2O_3	0.08	<0.01	0.1	0.1	0.1	0.05
SO_3	<0.01	<0.01	0.02	0.03	0.04	<0.01
$LI_{1000\ °C}$	24.8	31.1	24.4	24.3	26.7	25.63
$Ca(OH)_2$ (%)	97.4 [b]		94.4 [b]	96 [b]	55.2 [b]	55
$Mg(OH)_2$ (%)		98.5 [b]				45
S.S.(BET) (m^2/g)	15.5	6.6	17.5	41.2	28.8	11.4
Grading distribution						
1 μm	10	11	9	5	12	10
5 μm	52	37	44	38	58	52
10 μm	69	48	68	52	69	66
20 μm	82	60	85	65	78	77
32 μm	90	71	91	74	84	85
45 μm	95	89	94	80	88	93
63 μm	99.5	99.4	96	85	92	99
90 μm	99.9	100	98	90	95	100
160 μm	100	100	99.9	95	99.5	100
250 μm	100	100	100	98	100	100
500 μm	100	100	100	99	100	100

[a] The sample C_4 is a laboratory-made mix containing pure "analysis-grade" calcium and magnesium hydroxides in the same proportions as those of a hydrated dolomite.
[b] Value obtained by thermogravimetric analysis and calculated from DTA/TG curves.

Table 2
Chemical analysis and Bogue composition of the CPA CEM I cement used in mortar production

CaO	MgO	SiO_2	Fe_2O_3	Al_2O_3	SO_3	$LI_{1000\ °C}$	C_3S	C_2S	C_3A	C_4AF
64.8	0.8	21.3	4.3	3.7	2.7	1.2	62.0	14.0	2.5	13.1

Limes C_1 and C_2 have been hydrated under atmospheric pressure; their composition and purity are close to those of the pure calcium hydroxide. In the case of C_2, the tablets exhibit smaller size [15]. The specific surface area of C_1 (17.5 m^2/g) is close to that of calcium hydroxide (15.5 m^2/g), while it is not the case for lime C_2. The specific surface area of this lime (41.2 m^2/g) is 2.65 times higher than that of $Ca(OH)_2$. Lime C_3 has been hydrated under pressurised conditions [16]. This category of lime is a hydrated dolomite that differs from normally hydrated lime by: the presence of a small proportion of non-hydrated oxides (<8%), high plasticity, and a high water-retention capacity (which may be attributed to the small size of the crystals (<1 μm)).

Although lime C_2 is constituted of larger size crystals, this lime exhibits a specific surface area greater than those of the other limes. This phenomenon can be related to its more important porous volume [14].

Lime C_4 is a laboratory-made mixture containing the aforementioned pure "analysis-grade" magnesium and calcium hydroxides. These components were mixed in the same proportions as those of a hydrated dolomite (55% $Ca(OH)_2$ and 45% $Mg(OH)_2$).

Limes C_3 and C_4, whose chemical compositions are similar, appear on the scanning electron analysis as a cluster of fine particles composed of both $Ca(OH)_2$ and $Mg(OH)_2$. In the case of industrial lime C_3, which has been hydrated under pressure, this cluster appears to be more compact. Even if qualitative analyses were performed, it would be difficult to differentiate the platelets of calcium hydroxide from those of magnesium hydroxide. The specific surface area of lime C_3 is 2.5 times higher than that of C_4 [15].

2.1.2. Cement (Ce)

The cement used is CPA CEM I 52.5 (NF P 15-301). This cement was already used for previous works [14]. Its B.E.T specific surface area is 1.66 m^2/g. Its composition is presented in Table 2. This cement is a sulphate resistant cement. According to some authors this kind of cement can lead to a greater depth of carbonation [17], which could be attractive in the case of a lime–cement binder.

Table 3
W/B ratios as a function of substituted lime when mortars are made by holding workability constant

Ci/Ci+Ce (%)	Substituted lime					
	$Ca(OH)_2$	$Mg(OH)_2$	C_1	C_2	C_3	C_4
0	0.500	0.500	0.500	0.500	0.500	0.500
2	0.500	0.500	0.510	0.500	0.525	0.500
5	0.530	0.525	0.550	0.525	0.575	0.525
10	0.575	0.575	0.575	0.600	0.630	0.575

Ci is the mass of lime and Ce is the cement's mass.