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Fiber-reinforced lime-based mortars: Effect of zeolite addition

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HIGHLIGHTS

- Hydraulic lime is a good alternative to cement in manufacturing repair mortars.
- Use of short fibers can reduce plastic shrinkage and improve durability of masonry.
- Zeolitic additions further improve mechanical performances of hydraulic mortars.

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ABSTRACT

In a previous paper the authors demonstrated that adding glass fibers to hydraulic lime-based mortars leads to clear improvement in the post-cracking behavior. In order to enhance physical and mechanical performances of the above fiber reinforced mortars, the use of zeolitic addition was proposed. A phillipsite-rich tuff and a zeolite A [LTA] were selected and added in the mixtures. A significant decrease in open porosity and increase in mechanical behavior was achieved with each addition. In particular 20% of LTA produces an improvement of flexural and compressive strength up to 150% compared with fiber reinforced mortars without addition.

1. Introduction

The increasing attention for restoration and conservation of monuments and buildings of historical and/or architectural relevance and a more elevated environmental sensitivity (reduction of CO_2 emissions in atmosphere) has re-awakened the interest for lime-based binders and, in particular, hydraulic lime [1–3]. Hydraulic lime is a good alternative to cement in manufacturing repair mortars or plasters, according to its features of (i) compatibility with historical heritage and (ii) ability in thermo hygrometric control (i.e. transpiration, dehumidifying ability and insulation). Nevertheless lime-based mortars undergo an undesirable plastic shrinkage, most of all in dry environments, due to the fast water evaporation [4]. This could be overcome by the incorporation of short fibers, able to reduce plastic shrinkage and, at the same time, improve some properties of the building handwork, such as ductility, flexural strength and durability (in particular freeze–thaw resistance). In a recent paper [5,6] the authors have demonstrated that glass and basalt fibers are able to modify the mechanical behavior of hydraulic lime-based mortars. In fact, a significant improvement of toughness and flexural post-cracking behavior have been observed in reinforced mortars, regardless of the nature and amount of fibers. The best results, either as regards the maximum load or the toughness, have been obtained adding 2% of glass fibers. On the other hand, it is well known that this practice lowers the compressive strength of the hardened binder and increases the permeability.

An effective way to balance these changes is the use of supplementary materials, which can lead to a densification of the mortar [7]. In the last years much research has been carried out on the utilization of natural or synthetic zeolites, as pozzolanic materials, for manufacturing blended cements [8–10].

Zeolites are porous crystalline aluminosilicates, whose framework consists of interlocking SiO_4 and AlO_4 tetrahedra joined together in various regular arrangements through shared oxygen atoms [11]. The presence in this framework of open cavities in the form of channels and cages, which are usually occupied by guest molecules and extra-framework exchangeable cations balancing the negative charge created by the isomorphous replacement of Si^{4+} by Al^{3+} in the structure, gives to the material a high specific surface properties combined with useful adsorption and ion exchange properties [12–15]. The large specific surface area, joint with an intrinsic metastability, gives to the zeolites a

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pozzolanic activity, namely the ability to react with lime forming hydraulic compounds, i.e. hydrated calcium silicates (CSH) and hydrated calcium aluminate (CAH) phases, and harden in both aerial and aqueous environments [8].

Based on the good performances of the zeolites as pozzolanic materials, the present investigation aims at evaluating the effects of the incorporation of synthetic or natural zeolites on physical and mechanical properties of lime-based hydraulic mortars reinforced with glass fibers.

2. Experimental

A natural hydraulic lime (NHL) has been used to prepare the mortars. According to the European Standard [16] NHL is a commercial lime of the class 3.5. The material has been supplied by MGN (Schio, VI). A phillipsite-rich tuff (PRT) from Marano (Naples, Italy) and a sample of zeolite A [LTA] (Sasol Italy S.p.A.) have been used in the present investigation as pozzolanic additions.

The mineral composition of the PRT sample, with reference to the exchanging phases, was: phillipsite 46%, chabazite 5%, analcime 9%, smectite 10% (the remaining 30% included feldspar, pyroxene, biotite and various amorphous phases). The chemical composition of the above mentioned materials, summarized in Table 1, was elsewhere reported [5,17]. A siliceous fine aggregate (sand), supplied by Gras Calce company (Trezzo sull'Adda, Milan, Italy) was used, too. This material was previously subjected to XRD and grain size analyses. Particle size distribution was obtained by mechanical sieving, according to European Standards [18], and was reported in Fig. 1. E-glass chopped fibers (referred to as "G" throughout the text), supplied by Mapei company (Milan, Italy), were added to the mortars. Their main technical features are: $SiO_2/Al_2O_3 = 6.25$, mean length = 10 mm, mean diameter = 13 μm, Young modulus E = 75 GPa.

Mortar mixtures, whose composition is shown in Table 2, were manufactured adding to the solids suitable amounts of water to obtain a normal consistency and a good workability. In particular the water content of each mortar was set so as to obtain the same consistency (equal to 140 ± 10 mm), estimated through the flow table method, according to European Standard EN 1015-3 [19].

Binder to aggregate ratio (w/w) was fixed at 1:3. On the basis of the results obtained in a previous paper [5] G fibers were added at 2% (weight %). In order to improve workability and placement of the composite mortars, 1.5% (w/w) of a polymeric latex (Mapei) was added to each mixture. In particular, four fiber-reinforced mortars were prepared (referred to as T20, T30, Z20 and Z30 in Table 2), varying both the typology of pozzolanic addition (T = tuff, Z = synthetic zeolite) and the weight amount of hydraulic lime substituted by pozzolanic material (20% or 30% by weight). In addition, two reference mortars were also manufactured: a hydraulic lime-based mortar (referred to as REF in Table 2), and a hydraulic lime-based mortar reinforced with 2% (w/w) of glass fibers (referred to as G2 in Table 2). According to standard procedures, all the mortars were cured for 28 days in a climatic chamber (MSL, mod. Humichamber EC 125) in the following conditions: temperature, 20 °C; relative humidity, 95% during the first 7 days and 65% during the residual 21 days [21].

The main physical features (i.e. open porosity, apparent and real density) were carried out by mercury intrusion porosimetry [5], while water adsorption was determined in compliance with the water saturation test [20].

The mechanical characterization of the mortars was carried out following the European Standard UNI-EN-1015-11 [21]. In particular the three-point flexural tests were evaluated using an Instron 5566 compression machine, with a 5 kN load cell. Compression strength tests were performed on the two fragments of each specimen resulting from the preceding flexural test, using a Instron 8501, equipped with a 50 kN load cell. The loading rate in each test was 0.6 mm/min. All the experiments were carried out in triplicate.

X-ray diffraction analysis (XRD, Philips PW 1730 diffractometer) and scanning electron microscopy (SEM, Cambridge S440) have been used to identify and characterize the hydration products of all the experimental mortars.

The evaluation of the hydration and carbonation degree of each mortar was determined respectively from the $Ca(OH)_2$ and $CaCO_3$ content of the hydrated composites and a reference mortar (REF) by ignition method with thermogravimetric analysis [22,23], using a Netzsch STA 409 PCLuxx. The samples were heated on alumina pans from 20 to 1000 °C with heating rate of 10 °C/min under nitrogen atmosphere.

Table 1
Chemical analysis (%) of the hydraulic lime, synthetic zeolite (4A) and tuff (PRT) on anhydrous base.

Sample	SiO_2	CaO	MgO	Al_2O_3	Fe_2O_3	SO_3	Na_2O	K_2O	TiO_2
NHL 3,5	12.09	80.76	2.84	2.46	0.20	0.37	0.98	0.30	–
4A	42.38	–	–	35.80	–	–	21.86	–	–
PRT	58.52	3.01	1.11	19.10	4.60	–	3.44	9.39	0.52

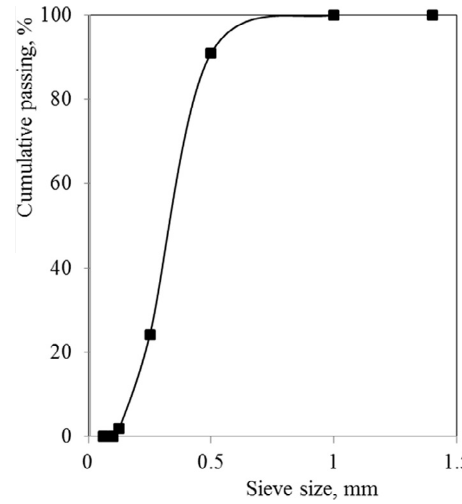

Fig. 1. Grain size distribution of the siliceous sand.

Table 2
Composition of the experimental mortars.

	Binder/sand ratio	Water/solid ratio	Glass fiber w/w%	PRT* %	LTA* %	Latex %
REF	1:3	0.22	–	–	–	–
G2	1:3	0.18	2	–	–	1.5
T20	1:3	0.18	2	20	–	1.5
T30	1:3	0.18	2	30	–	1.5
Z20	1:3	0.18	2	–	20	1.5
Z30	1:3	0.18	2	–	30	1.5

* This value represents the amount of lime, by weight, substituted by pozzolanic materials.

Table 3
Physical properties of mortars.

	Apparent density (g/cm^3)	Real density (g/cm^3)	Porosity (%)	Water absorption (%)
REF	1.59*	2.47*	35.6*	22.39
G2	1.44*	2.64*	45.2*	30.11
T20	1.50	2.06	27.8	18.35
T30	1.50	2.11	28.8	19.21
Z20	1.63	2.30	29.2	17.93
Z30	1.53	2.20	31.2	20.43

* These data have already been reported elsewhere [5].

3. Results and discussion

3.1. Physical properties

Table 3 reports the physical parameters obtained for all the manufactured mortars. As previously reported and discussed [5] the porosity of fibro-reinforced mortar (G2) is widely greater than the reference sample (REF). The incorporation of 2% of glass fibers in the hydraulic lime mortar promoted an increase of 27% of the open porosity. This is due, in general, to the interruption of the continuity of material microstructure, as a result of the inclusion of heterogeneities in a homogeneous body. Specifically, glassy fibers, modifying the mortar workability, promote the formation of micro cavities in the interfacial transition zone between lime paste and fibers, hindering the hydration or carbonation of lime paste. Additional causes of increase of porosity might be some surface hydrophobicity, due to pre-treatments of fibers or excess of gas trapped in the blend. When zeolitic materials (both natural or synthetic) were added in the blend, a marked reduction in