Journal of Sustainable Cement-Based Materials, 2019
Vol. 8, No. 4, 214–227, http://doi.org/10.1080/21650373.2019.1615012

Properties of multifunctional lightweight mortars containing zeolite and natural fibers

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The article focuses on the development of innovative and multifunctional mortars with low environmental impact for indoor applications acting as passive systems to moderate extremes of humidity and to lower the concentration of pollutants. Mortars are manufactured by keeping constant the water/binder ratio, using sand as reference aggregate, and by replacing the total volume of sand with zeolite. In some mixes the aggregate, is also at 25vol% by wool natural fibers. Regardless lightness, zeolite thanks to its pozzolanic activity, helps to improve the compressive strength of mortars manufactured with wool fibers. In addition, the combination of zeolite and wool increases the hygro-thermal performance of mortars: water vapor resistance factor (22% lower than the reference), moisture buffering value (100% higher than the reference), and thermal conductivity (66% lower than the reference), respectively. Depolluting properties of zeolite-based mortars, in terms of adsorption capacity, are 65% lower than that of reference mortar.

Keywords: Natural fibre-based composites; mechanical strength; hygro-thermal properties; depolluting capacity

1. Introduction

The development of sustainable building materials has become of primary importance in the construction industry since more than 40% of global energy is consumed by the construction sector [1–3].

In order to control this problem, related laws and directives induce to design buildings more sealed, causing a poor Indoor Air Quality (IAQ). On the other hand, nowadays, people are spending up to 90% of their time indoor [4], increasing the risk of exposure to unhealthy environment [5]. A great number of indoor sources emit indoor pollutants, such as volatile organic compounds (VOCs), causing health problems, including drowsiness, headaches, sore throat, and mental fatigue [6, 7]. Not only pollutants, but also temperature and relative humidity (RH) are relevant factors for indoor comfort and health. For example, it is reported that the optimal indoor RH is around 50% [8], whereas the exposure to lower or higher levels can cause discomfort conditions to occupants: low RH induce drying of mucous membranes and skin, high RH can damage occupants' health and indoor surfaces by promoting biological growth (moulds, bacteria, fungi) [9].

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Conventional strategies for IAQ control are active systems, but they require energy to work, increasing the total energy consumption of buildings [10].

Building materials offer an opportunity to improve IAQ with minimal energy use. Different materials such as unconventional aggregates, fillers and fibers can potentially act not only as insulation materials, but also as passive systems to moderate extremes of humidity [11] and/or to lower the concentration of pollutants [12, 13]. The addition of walnut shells in panels improve their ability to remove VOCs and formaldehyde and to buffer humidity in indoor air. This is attributed to the porous surface of walnut shell that increases the specific surface area of the panel, thus its adsorption capacity [14]. Studies have been conducted also to exploit the highly adsorbent properties of pozzolanic materials [15]. Pozzolanic materials, which are rich in SiO_2 and Al_2O_3 in poorly crystallized and porous form, are widely used in cementitious materials to enhance the mechanical properties and durability of final products [16, 17].

Zeolite is one of the most effective pozzolanic material [18] and one of the most adsorptive material to reduce VOCs, resulting efficient as it is [19], in membrane [20] as well as unconventional aggregate/filler in both, inorganic [21] or organic binders composites [13]. Zeolite can also act as heterogeneous catalyst, as adsorbent and as molecular sieve in gas separation processes [20].

The application of coatings and finishes can also be a solution to increase [22, 23] up to half [24] the moisture buffer performance and water vapor permeability of the wall assemblies. Moreover, a statistical study conducted in 78 rooms of 46 newly built timber-framed houses has demonstrated that permeable and hygroscopic structures considerably improve the perceived IAQ [25].

In concrete and mortars, fibers are used to provide cracking control at early ages and increase fracture strength [26]. Natural fibers and shives are also used for insulation purposes. Hemp fibers and shives give a quite low value of thermal conductivity (0.2 W/(m·K)) [27] to a mineral matrix based on lime [28] or cement [29]. Also, wood shavings into a sand–cement mixture increase the total porosity of mortars with a consequent increase in thermal insulating properties [30].

In the same way, some animal fibers, such as sheep's wool, are now applied as an alternative insulating material for buildings [31, 32]. In fact, wool is a renewable material, since a sheep annually produces on average between 2.3 and 3.6 kg of raw wool that should be sheared for its health. However, about 75% of the wool produced by European sheep farms cannot be used by the textile industry and by being a special waste, it needs to be sterilized at 130 °C before disposal [33]. The amount of this waste, to which also the wool wastes of textile industries (e.g. fitted carpet) should be added, has a big economic importance and a worldwide distribution, as demonstrated by the presence of plenty of companies in the world that deal wool wastes [34]. The composition of wool by weight is (approximately): 82% of keratin proteins, 17% of "nonkeratinous" (with relative low cystine content) and 1% of other substances, non-proteinaceous materials (waxy lipids plus small amount of polysaccharide material) [35]. Natural proteins are distinguished in fibrous proteins and globular proteins, and the first (α and β keratine, collagen, elastin) are insoluble in water [36]. Moreover, the elastic modulus of wool fibers (1–4 GPa) is comparable to the modulus of plastic one used to reinforce cement-based composites [33, 37]. Therefore, the high amount of waste wool could be effectively used to reinforce mortar instead of plastics, rather than landfilled.

Nevertheless, to the authors' knowledge experimental investigations on the use of wool as fiber-reinforcement in lime-based composites cannot be found in the technical literature and only a paper has been recently published on wool fibers in cement-based mortars [33]. Araya-Letelier et al. [26] added pig hair in cement mortars with the improve of impact strength, abrasion resistance, plastic shrinkage cracking, age at cracking and the decrease of crack widths as fiber volume increases. Therefore, the tests performed on lime mortars reinforced with wool fibers, as described for the first time in the following sections, can be very useful to create an additional and more sustainable market for this valuable resource.

In particular, this research focuses on the development of innovative and multifunctional mortars for indoor application as renders or panels with low environmental impact able to improve comfort and health of occupants. Taking into account the sustainability, hydraulic lime was used as binder, since it is less pollutant than Ordinary Portland Cement (OPC), due to the lower temperatures required for its production (about 1000 °C instead of 1450 °C) [38]. In particular, this article investigates the possible interaction between lime, wool, and zeolite in mortars, thus different constituents that until now have been used only separately (i.e. wool insulating panels or lime-zeolite mortars). The article compares the fresh and hardened states properties of mortars in terms of workability, mechanical strength and microstructure. Hygro-thermal properties such as permeability to water vapor, moisture buffering capacity (MBC) and thermal conductivity are measured. Depollution properties are evaluated by monitoring the adsorption of a known quantity of methyl-ethyl-keton (MEK) by mortar specimens in a closed box.

2. Experimental

2.1. Material

The commercial product PLASTOCEM® (Italcementi S.p.A.), a hydraulic lime (L) HB 3.0, according to UNI EN 15368, with a bulk density of 2650 kg/m^3, was used as binder.

A calcareous commercial sand (Gruppo Cava Gola Della Rossa S.p.A.) was used as reference aggregate (S); the bulk density is 2650 kg/m^3 and specific surface 5 m^2/g. The water absorption of aggregates was estimated using five oven-dry samples immersed in water for 24 h and then dried superficially with paper towels to remove the excess of water, and to ensure the saturation of only the inner porosities. The estimated value of water absorption to reach saturated surface dry condition (s.s.d.) for sand is 5%.

Zeolite (Z) (SaMore S.r.l) with minimum Cation Exchange Capacity of 150 meq/100 was used as unconventional porous aggregate to replace the total volume of sand. Zeolite has a lower density, a higher specific surface, and a higher water absorption than sand, equal to 1600 kg/m^3, 600 m^2/g, and 22%, respectively.

Wool fibers (W) were provided by Nelflex®. The maximum length of fibers is 4.5 mm, the density is 100 kg/m^3, and the water absorption is 100%. The water absorption of fibers was measured with the same method used for aggregates, as already reported by other authors [26].

Figure 1 shows the grain size distribution (from 0 to 1 mm) of aggregates and the visual aspect of calcareous sand, zeolite and wool fibers.

2.2. Preparation of mortars

Water/binder ratio of mortars was kept constant at 0.54 by mass. Aggregate/binder ratio was 3.5 by volume. Sand was used as reference aggregate and the corresponding reference mortar was labelled as L-S. To improve the thermal behavior, from this mix design, 25% of aggregate volume was replaced with wool natural fibers due to their well-known thermal properties (L-S-W). In order to improve the positive impact of the mortar on IAQ, the volume of

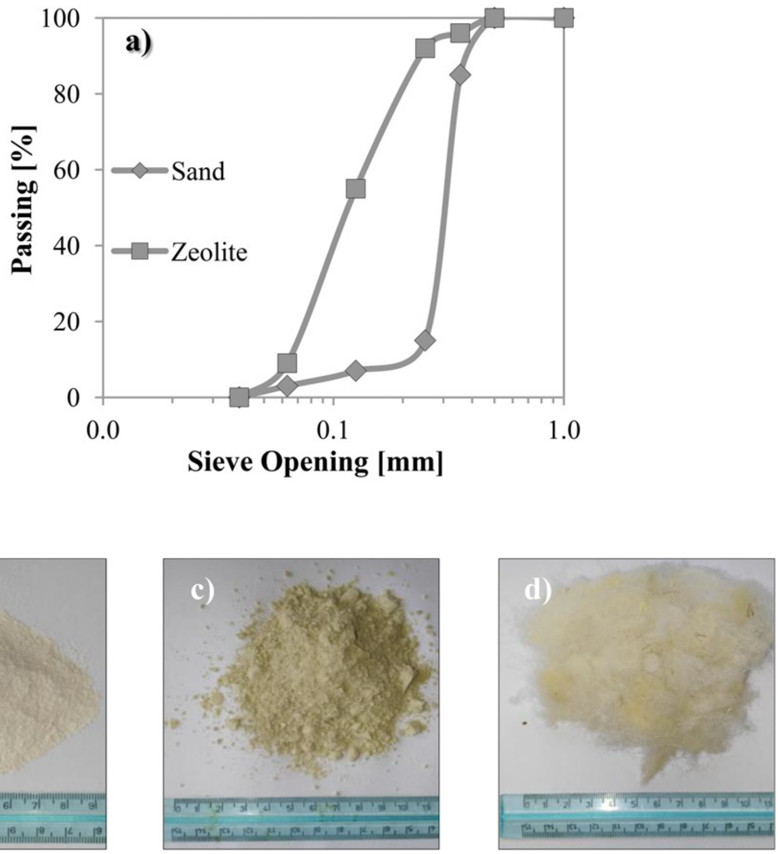

Figure 1. Aggregates and natural fibers. (a) Grain size distribution of calcareous sand and zeolite. (b) Calcareous sand. (c) Zeolite. (d) Wool fibers.

reference aggregate was also completely substituted by zeolite (L-Z). Again, also 25% of zeolite volume was replaced by wool fibers. Both aggregate and fibers were added to each mix in s.s.d. condition. Table 1 shows the mix design of mortars and the obtained workability.

During the curing period, the temperature (T) was (20 ± 2)°C and the RH was (95 ± 5)% for the first 7days and then (60 ± 5)% for the following 21days.

2.3. Methods

2.3.1. Fresh state properties

UNI EN 1015-3:2007 test standard was used to investigate the workability of mortars. The slump flow test was performed using a truncated cone (100–70 mm base-top diameter, and 60mm height). The reported values are the average value of the two measured perpendicular diameters.

2.3.2. Microstructural properties

In order to correlate the obtained results with microstructure, mortars were observed by Scanning Electron Microscopy (SEM) applying a ZEISS 1530 SEM (Carl Zeiss) equipped with a Schottky emitter, with two different secondary electrons (SE) detectors (the in-lens and the Everhart-Thornley) and operating at 10 keV.

Also, the pore size distribution of mortars was investigated by means of Mercury Intrusion Porosimetry (MIP) by using a Thermo Fisher, Pascal series 240) with 0.1–200 MPa range pressures. Samples of about 1 cm^3 were taken from the bulk of specimens after 28 days of curing. Tests were repeated three times and the average results are reported.

2.3.3. *Density and mechanical properties*

Hardened state properties were evaluated in specimens cured for 28 days. The oven-dry density was calculated by measuring the weight and the volumetric dimensions of prismatic specimens ($4 \times 4 \times 16\,cm^3$) previously dried at $T = 105\,°C$ until constant weight was reached. Compressive and flexural strengths were measured according to UNI EN 1015-11:2007 by means of a "Galdabini" hydraulic press with a precision of 1%. At least three prismatic specimens ($4 \times 4 \times 16\,cm^3$) were tested and the average results are reported.

2.3.4. *Hygrometric properties*

Hygrometric performance of mortars was evaluated both in static and dynamic conditions.

In static case, water vapor permeability test was performed according to UNI EN 1015-19:2007 and data processed according to UNI EN ISO 12572:2007. Three cylindrical mortar specimens ($d = 12.5$ cm; $h = 3.0$ cm) were exposed inside a climatic chamber at T (20 ± 2)°C and RH (50 ± 5)% after sealing the specimens on a sample-holder filled with a saturated solution of potassium nitrate (KNO_3) which guarantees a RH = 93 ± 3% at $T = 20 \pm 2\,°C$. Differences of RH between the surfaces of specimens generate a water vapor flux from inside the sample holder to outside. The flow is maintained unidirectional by sealing the side surface of specimens. When the flux reaches the stationary condition, the vapor diffusion resistance factor μ, defined as the ratio between the vapor permeability of stagnant air δ_a (kg/(Pa·m·s)) and the vapor permeability of the material δ_p (kg/(Pa·m·s)) at the same temperature and pressure [39], can be evaluated.

In dynamic case, a simplified version of NORDTEST was used to study the MBC of mortars [40]. The practical moisture buffering value (MBV) (g/(m^2% RH)) was calculated as the amount of moisture changed by the material per surface unit and RH gradient [27]. Three cylindrical mortar specimens ($d = 12.5$ cm; $h = 3.0$ cm) were pre-conditioned inside a climatic chamber at T = (20 ± 2)°C and RH = (50 ± 5)% until equilibrium was reached. Then specimens were cyclically exposed to high levels (75% for 8 h) and low levels (33% for 16 h) of RH to simulate daily variations in RHs. The exposure to different levels of RH was carried out by placing the specimens inside two climate boxes containing a saturated solution of magnesium chloride ($MgCl_2$, RH = 33%) and sodium chloride (NaCl, RH = 75%), kept at T = (20 ± 2)°C during the test. The duration of the entire cycle was 24 h and after each exposure the weight of specimens was measured in order to know the amount of water vapor absorbed or released.

2.3.5. *Thermal properties*

Thermal conductivity of mortars was tested on three cylindrical mortars specimens ($d = 12.5$ cm; $h = 3.0$ cm) with a heat analyser ISOMET 2104, with a non-stationary method. Specimens were cured as previously described and then stored in a T–RH controlled chamber at T = (20 ± 2)°C and RH = (50 ± 5)%. Tests were conducted under these conditions in order to better simulate the behavior of mortars in a real indoor environment [41].

2.3.6. *Depolluting properties*

Depolluting properties were evaluated monitoring the decay of a known quantity of MEK, adsorbed by specimens, in a closed borosilicate glass box (16.5 l) during

Table 1. Mix proportions (kg/m^3) and workability (mm) of mortars.

ID sample	Hydraulic lime kg/m^3	Sand kg/m^3	Zeolite kg/m^3	Water kg/m^3	Wool fibers kg/m^3	Slump mm
L-S	437	1535		256		120
L-S-W	437	1151		256	108	105
L-Z	437		926	256		108
L-Z-W	437		695	256	108	104

time [21]. MEK was chosen as tracer for its high environmental stability. Cylindrical specimens ($d = 3.4$ cm, $h = 4$ cm) cured for 28 days were placed inside the box. The box was provided by a fan in order to guarantee a continuous air recirculation. MEK was injected and then air samples were collected by a micro-syringe and analyzed by means of a gas chromatograph (Flame Ionization Detector, injector split 1:15, carrier flow 2 mL/min, capillary column, 25 m × 0.32 mm, 0.52 μm cross linked methyl siloxane, isotherm condition 40 °C). 50 μL of MEK were initially injected into the test box, corresponding to 2402 mg/m^3, approximately four times the threshold limit value [42]. Tests were conducted for 120 min. After 20 min from the initial injection, data started to be consistent because all MEK was vaporized and the MEK concentration inside the box was monitored for 120 min. Three measurements were repeated, and the average results are reported in terms of ratio between the percentage of detected concentration (C_i) and the initial concentration (C_0) in time.

3. Results and discussions

3.1. Fresh state properties

Table 1 shows that all mortars have the same workability class, with a stiff consistence, according to UNI EN 1015-6:2007, since the slump flow is always lower than 140 mm. The same workability is obtained by adding both aggregates and fibers in s.s.d. condition.

3.2. Microstructural properties

The interfacial transition zone (ITZ) between lime and different aggregates and the morphology of aggregate surfaces are observed by means of SEM (see Figure 2). In Figure 2a the image obtained by observing a fragment of Lime–Sand interface is reported. The interface between the two components is easily observed (Figure 2b) indicating that the quality of the ITZ between natural sand and lime appears quite poor. In fact, natural sand particles show smooth surface, which does not allow good adhesion with lime paste and the mechanical interlock appears scarce.

In Figure 2d, the image obtained by observing a fragment of the Lime–Zeolite mortar is reported. In this case the identification of the interface between aggregate and binder (Figure 2c) is very difficult and the surface of the zeolite particle appears totally covered by a layer of lime paste. There is a perfect adhesion between zeolites particles and the surrounding lime paste with an optimum mechanical interlock. Literature already reports a superficial pozzolanic action of zeolite with the calcium hydroxide present in the binder paste which can further improve the mechanical strength and Lime–Zeolite interface of lime mortars [18, 43]. Amir Elsharief et al. [44] showed that, on the contrary to what expected, the durability of lightweight aggregate concrete was higher than that of the normal aggregate concrete due to the denser ITZ around the lightweight aggregate. This explains the better mechanical performances of Lime–Zeolite mortar with respect to Lime–Sand mortar regardless of its lightness, as discussed in Section 3.3.

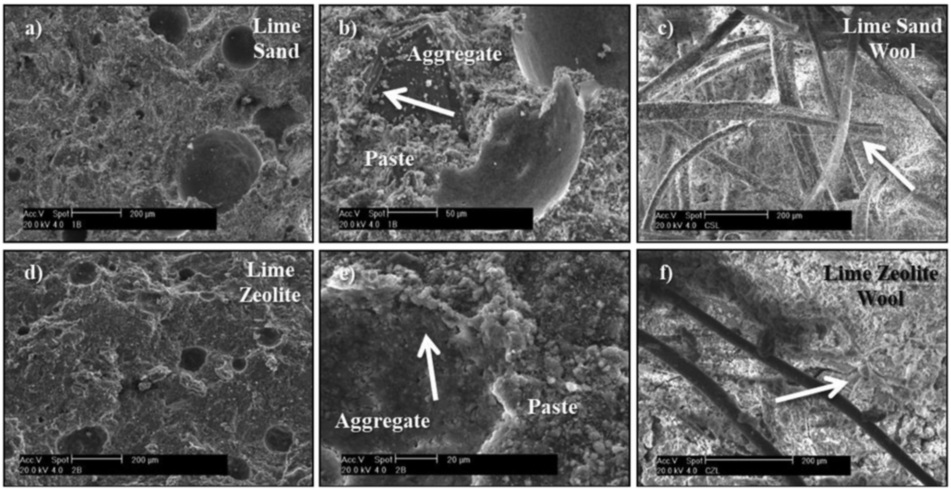

Figure 2. SEM images of mortars. (a) L-S. (b) L-S: poor ITZ between calcareous sand and lime paste (c) L–S–W: zoom on wool fibers and lime paste (d) L-Z. (e) L-Z: optimum ITZ between zeolite sand and lime paste (f) L–Z–W: zoom on wool fibers and lime paste.

The addition of fibers does not imply a worsening effect in the microstructure. The arrows in Figure 3c, f highlight the good ITZ between paste and fibers, which result well dispersed in the matrix.

The percentage of total open porosity of mortar is shown in Figure 3a. As expected, L-S mortar has the lowest percentage of voids (about 31%) with a unimodal pore size distribution (Figure 3b). The addition of fibers implies a 5% more porosity (about 32% of total open porosity for L-S-W) and a bi-modal distribution: the presence of fibers generates a second peak with a higher pore diameter than the first peak. Despite zeolite mortars, with and without fibers, show the best compressive strength (see Section 3.3), their total pore volume is about 41% (L-Z) and 44% (L-Z-W), which are 33% and 44% higher than L-S mortar, respectively.

The pore size distribution curve of L-Z is bi-modal, characterized by peaks with lower diameter than S-Z. Also, in this case, the inclusion of wool introduces an additional peak around 5.42 μm (the distribution is tri-modal).

3.3. Density and mechanical properties

The replacement of sand volume with zeolite and the addition of wool fibers imply a decrease in density, as expected. The reference mortar has a density of 1850 kg/m^3 (Figure 4a). The addition of wool fibers (L-S-W) leads to a decrease in density of 13%. Using zeolite as aggregates instead of sand decreases the mortar density of 24% compared to L-S. The combined use of zeolite and wool fibers permits to obtain a lightweight mortar (according to UNI EN 998-1:2010) with the lowest density, 33% lower than the reference mortar, equal to 1180 kg/m^3.

In case of sand-based mortar, the lower the density, the lower the compressive strength of mortars, as shown in Figure 4b. In fact, compressive strength results show that the use of wool fibers (L-S-W) halves the mechanical performance. Reductions in compressive strength due to fibers incorporation have been previously reported [45].

However, the use of zeolite as unconventional aggregate [21] thanks to its optimum ITZ with lime paste (Figure 2) owing to its well-known pozzolanic

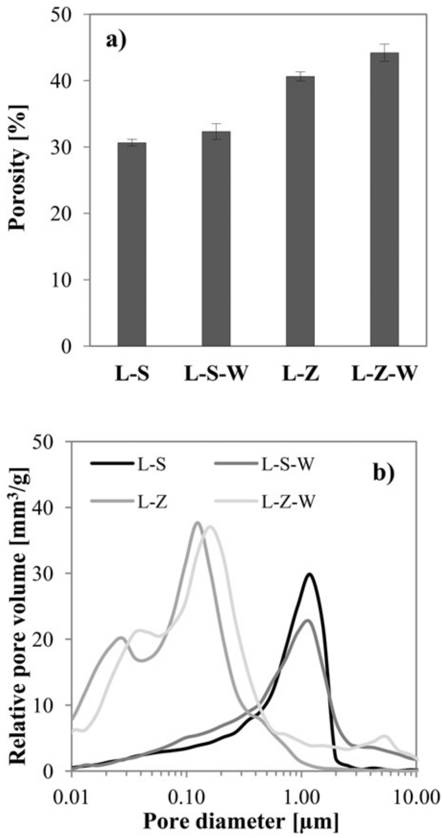

Figure 3. Porosity of mortars. (a) Percentage of total open porosity. (b) Pore size distribution curves.

property [18, 43], permits to increase the mechanical performances of about 100% (L-Z), even if Lime–Zeolite is up to 20% lighter than Lime–Sand. Therefore, the combined use of zeolite and wool fibers permits to recover the reduction of compressive strength due to wool fibers addition: compressive strength becomes 5% higher in case of L-Z-W compared to the reference mortar.

On the other side, the addition of wool fibers enhances the flexural strength (R_f) of mortars (Figure 4c). L-S-W has about 30% higher flexural mechanical strength than L-S. Studies have already demonstrated the bridging properties of vegetables fibers in cracked cementitious composites [46]. During the current experimentation, not

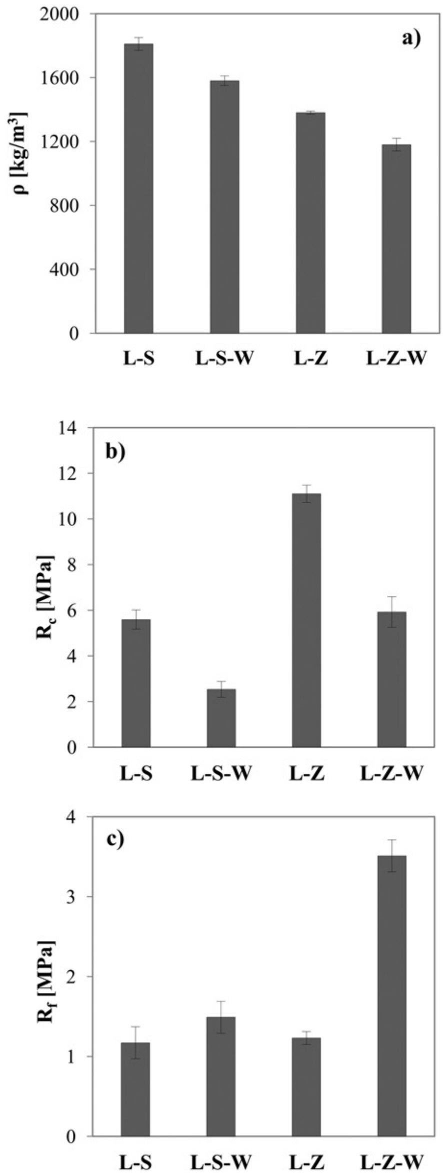

Figure 4. Properties of mortars. (a) Density, ρ. (b) Compressive strength, R_c. (c) Flexural strength, R_f.

only the bridging properties but also the possible increase in R_f have been registered. The increase in flexural strength has also been reported by other authors that used natural animal fibers with medium/high modulus of elasticity [26]. The use of zeolite as unconventional aggregate slightly improves (for only 5%) the flexural strength. Again, in this case the best behavior has been detected in L-Z-W mortar, with a R_f value up to two times higher than reference mortar.

However, since the chemical behavior of wool is related to the isoelectric point and wool fibers have an isoelectric pH around 5, they resist better to acids than bases [35, 36], such optimization must be also supported by a study concerning the chemical damage of wool in alkaline environments.

3.4. Hygrometric properties

Figure 5a shows the results obtained by the water vapor permeability test in terms of water vapor diffusion resistance factor (μ). The lower the factor, the higher the permeability. L-S mortar has the highest value of μ, meaning that this mortar has the lowest water vapor permeability. L-S-W has a μ value 6% lower than the reference mortar. L-Z and L-Z-W mortars have a very low value, slightly higher than 11, which are about 20 and 22% lower than the reference mortar, respectively.

According to Poiseuille's law, permeability in porous materials is affected not only by total porosity, but also by the pore size distribution and tortuosity of the microstructure [47]. L-S has the lowest value of porosity and the increase in permeability of mortars with the use of zeolite depends on the higher porosity. In particular, the greater the threshold pore diameter, the higher the permeability, which is proportional to the product of porosity and square diameter of the main mode pore [48]. The addition of wool implies changes to the pore structure of mortar. L-S-W and L-Z-W have an additional peak in pore size distribution, with a higher presence of pores with higher diameters than the same mortar without the wool fibers. Therefore, L-S-W and L-Z-W have higher permeability than L-S and L-Z, respectively.

The MBV of mortars is shown in Figure 5b. L-S has the lowest exchange of

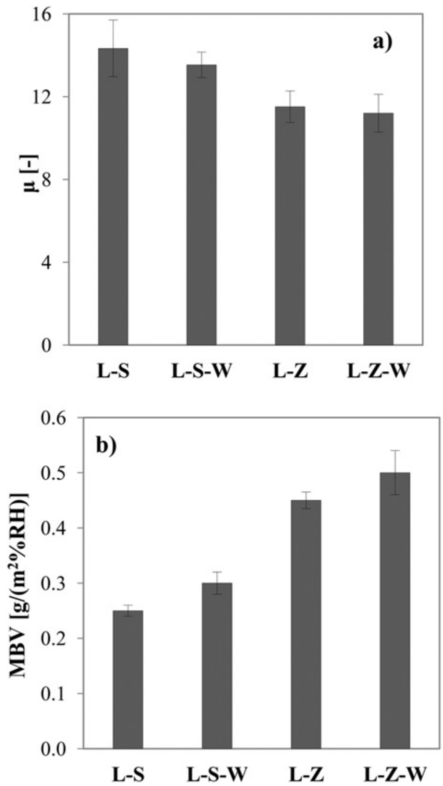

Figure 5. Hygrometric properties of different mortars. (a)Water vapor diffusion resistance factor μ. (b). Moisture buffering value (MBV).

water vapor. L-S-W has a slightly higher (around 20%) MBV value than the reference. When zeolite is used, mortars have higher MBV values (around 80 and 100%) than those prepared with sand. This behavior has two main reasons: the former is related to the porosity of mortar, the latter to the polarity of unconventional aggregate. The higher the specific surface of mortars, and consequently its porosity, the higher the ability of the material to uptake and release water vapor [49]. Moreover, the use of a polar adsorbent as zeolite, with a great affinity with water [50], enhances the capability of the mortar to act as a moisture buffer.

If results of water vapor permeability and MBC tests are evaluated, a linear correlation can be obtained (Figure 6). This relation confirms previous studies where specimens with the highest transpiration capacity possess also the highest MBC [51], since the higher the porosity of mortars, the higher the moisture penetration depth [22, 41]. As Figure 7 clearly shows with good linear correlations, the higher the porosity, the higher the permeability (lower μ value), and also the MBC, hence the MBV value.

3.5. Thermal properties

The thermal conductivity (λ) results are shown in Figure 8. The L-S mortar has the highest value of thermal conductivity. With the addition of wool fibers, the λ value decreases of about 36%. Again, the use of zeolite implies a lower (around 46%) value of thermal conductivity than the reference mortar. Also, for this property the best behavior is detected in case of L-Z-W mortar, with a value of 0.19 W/(m·K), which is 66% lower than that of the reference mortar. Many authors have indicated the relation between thermal conductivity and density: the lower the density, the lower the thermal conductivity [52–54]. This is due to the porosity of mortar itself.

Porosity is the main parameter influencing the hygro-thermal behavior of mortars. As Figure 9 shows the higher the porosity,

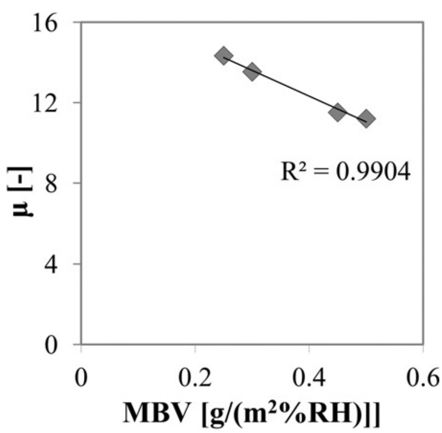

Figure 6. Linear correlation between water vapor resistance factor μ and MBV of different mortars.

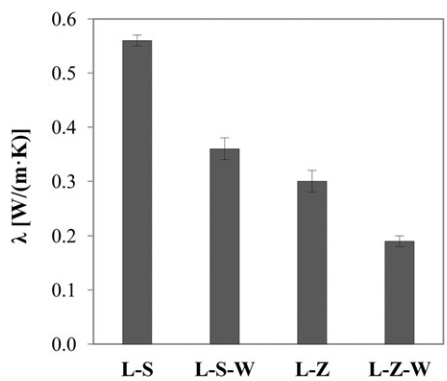

Figure 8. Thermal conductivity λ of mortars.

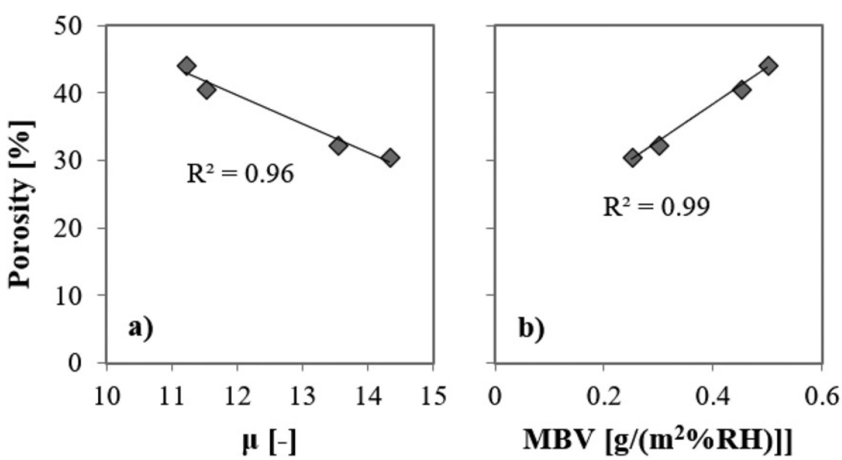

Figure 7. Linear correlation between porosity and hygrometric properties of mortars. (a) Porosity and water vapor resistance factor, μ. (b) Porosity and MBV.

the higher the insulation capacity (lower λ). However, a lower correlation coefficient is detected when porosity and thermal conductivity are interrelated with respect to that correlating porosity with μ and MBV (Figure 7). This can be explained by the fact that the thermal conductivity of mortars is affected not only by the total porosity but also by the thermal properties of their constituents [55], such as aggregates [56] and fibers.

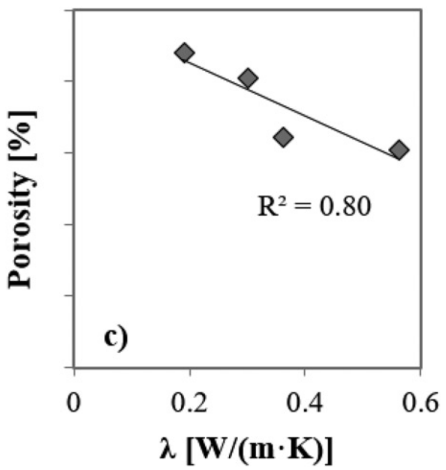

Figure 9. Linear correlation between porosity and hygrothermal properties of mortars. (c) Porosity and thermal conductivity, λ, of different mortars.

3.6. Depolluting properties

Figure 10 shows the trend line of residual percentage of MEK inside the test box where the depolluting capacity of specimens was evaluated. The trend line evaluation starts after 20 min from the first MEK load because this time is necessary for the complete vaporization of the tracer [13, 57].

As shown in previous studies, L-S mortar does not show relevant adsorbent activity [21]. The addition of wool fibers does not modify the depolluting properties of mortar: adsorbent properties are not detected. The use of zeolite, owing to the high specific surface and the adsorbent properties [13], can improve the depolluting ability of mortars, with and without wool fibers. In fact, after 2 hours with L-S-W and L-Z-W mortars the residual concentration of MEK inside the box is about 40%, namely 65% lower than that detected with L-S mortar.

4. Conclusions

Lightweight mortars for indoor applications are manufactured by replacing the total volume of calcareous sand with zeolite as unconventional aggregate. Wool fibers are

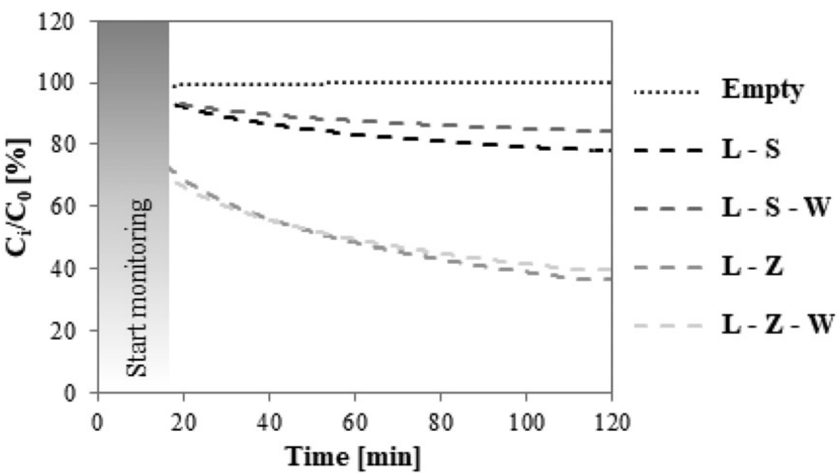

Figure 10. Methyl-ethyl-ketone (MEK) residual concentration Ci/C0 inside the box containing different mortars, as a function of exposure time.

also added, substituting 25% of aggregate by volume, in order to obtain sustainable and multifunctional composites. Mortars are assessed in terms of mechanical and physical characteristics and the influence on the IAQ is evaluated in terms of hygrothermal and depolluting behavior of mortars.

The obtained results show that zeolite, lime and wool can be combined in lime-based mortars to produce a new composite material for indoor applications with enhanced functionalities compared to those of traditional mortars manufactured with conventional sand thanks to:

- an improved mechanical performance, namely 5 and 200% higher compressive and flexural strength, respectively, owing to the excellent ITZ between zeolite and lime and also to the presence of fibers.
- a 22% higher breathability;
- a two times higher hygroscopic buffering capacity;
- a three times lower thermal conductivity;
- a three times higher depolluting ability.

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