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Influence of binders and aggregates on VOCs adsorption and moisture buffering activity of mortars for indoor applications

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ABSTRACT

The implementation of energy efficiency measures leads to more tightly sealed buildings. These energy-saving measures directly worsen indoor air quality leading to increased humidity and concentration of pollutants as Volatile Organic Compounds (VOCs). Our work compares the de-pollution efficiency and moisture buffering capacity of five mortars for indoor applications. Methyl-ethyl-ketone (MEK) is chosen as pollutant model. The effect of binders (cement, cement + air-entraining admixture, lime) and aggregates (sand, zeolite, perlite) on the mechanical properties, water absorption and morphology of mortars was also evaluated. All mortars adsorb MEK during the first period, but only those manufactured with lime–zeolite do not saturate after 30 min with a de-pollution efficiency of about 85% after 24 h. The Moisture Buffering Capacity (MBC) of lime mortars is three times higher with respect to that measured in cement mortars. The MBC of lime–zeolite mortars is double with respect to that measured in lime–sand mortars.

1. Introduction

A more comfortable and healthier indoor environment during the service life of a building is becoming more and more critical because humans spend much of their time indoors [1] but the implementation of energy efficiency measures [2] leads to more tightly sealed buildings with a limited amount of escaping air. These energy-saving measures directly worsen indoor air quality with increased potential for exposure to a wide variety of indoor pollutants such as Volatile Organic Compounds (VOCs), O_3, NO_2 and SO_2 [3]. In addition, the building envelope is no longer responsible for transmitting vapour towards the outside. Due to the varying loads, indoor humidity exhibits significant daily or seasonal variation. High values of relative indoor humidity may decrease the inhabitants comfort and health [4–10], cause the deterioration of building materials with higher maintenance costs [11], play a crucial role on mould growth and biological organisms proliferation [12,13] and decrease acoustic [14] and thermal resistance of materials, thus increasing energy consumption for heating and cooling [15].

Currently, the improvement of indoor air quality generally involves active systems that have a substantial energy impact [16]. Moreover, in small, low-density interiors, they are a source of noise for people indoors.

Therefore, to meet the demands of healthier indoor environments in conjunction with energy efficiency goals, new approaches for indoor air cleaning are required. The development of strategies based on passive systems must play a fundamental role in the achievement of adequate indoor climatic conditions, under criteria of sustainability [2,17].

Reactive building materials offer an opportunity to provide indoor air cleaning with minimal energy use and surface deposition velocities of O_3, NO_2 and SO_2 were measured and modelled for a range of material surfaces typically found indoors [18–20]. Ozone removal depends weakly on the air exchange rate and strongly on the panel material, [2] such as paper [21], active carbon [20] and unpainted gypsum wallboards (GWB) [2]. Also perlite-based ceiling tiles, natural cork wall-coverings, wheat boards [22], modified zeolites, clays and cellulose powders, improve the removal of ozone. Recent results have shown that the inclusion of activated carbon in cement mixes improves ozone removal efficiency [2].

Indoor passive removal of O_3 is easy to obtain thanks to the reactivity of this gas with many surfaces [21]. However, many pollutants other than ozone are of concern indoors. A composite material effectively removed formaldehyde passively in chamber tests in a field study in Japanese residences [17].

Passive removal of NOx and VOC is well established outdoors where the UV fraction of the sunlight allows their photo-degradation if the passive barrier is treated with titanium dioxide (TiO_2)

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[23,24]. Indoors, the photo-degradation technique with TiO_2 requires UV lamps and is therefore limited to road tunnels [25]. Studies related to the ability of removing VOCs with passive strategies in mortars and concretes in the absence of catalysis are very limited.

In principle, all solids may be active in the sorption process, but if the solid has a large specific surface area (typically greater than 3×10^5 m^2/kg) then the quantity of substance capable of binding assumes considerable proportions [26–28]. Uses of porous materials such as activated carbon [17] or zeolite are well-established methods to control indoor VOCs. They possess special properties such as ion exchange, molecular sieves, large surface area and catalytic activity [26–31] and are frequently employed in traditional air purification systems [32,33].

Among traditional binders, gypsum in particular is an effective passive removal material (PRM) [2]. Recently, it has been demonstrated that also traditional cementitious materials could participate in purifying ambient air containing VOCs such as formaldehyde, since concretes and mortars are solids which can be considered as "breathing materials" which absorb and/or adsorb many compounds [34].

Indeed, by coupling cementitious materials with adsorbent materials such as aggregates/fillers this cleaning action could be enhanced. Recent results [35] have shown that a very low addition of active carbon (0.01% by cement weight) greatly enhances the NO_2 removal efficiency of concrete.

The use of zeolitic materials for the production of lightweight aggregates in concrete applications is already known [36,37] thanks to their very low commercial cost and pozzolanic activity [38], but it is not common in Europe. In China, natural zeolite is added to improve fresh and hardened concrete properties such as durability and to act as an anti-bacteria agent [37]. However, the sorption capacity of zeolites for indoor pollutants [39] when applied in mortars/plasters based on traditional binders (lime/cement) has not been investigated yet.

Porous adsorbent materials can also control humidity levels in indoor climates without adding energy costs to the building thanks to their hygroscopic abilities measured as Moisture Buffering Capacity (MBC) [41,10,15]. Many experiments have shown the hygroscopic buffering properties of wood based materials [15,42,43], bentonites [44], cellulose based and highly absorbing materials [45]. However, only a few papers report the effect of adding porous adsorbent aggregates on the moisture buffering ability of mortars [37,26,46,47].

The scope of this work is to investigate innovative multifunctional mortars for indoor applications, able to fulfil not only the traditional requirements but also to act as possible passive filters for VOCs and as hygroscopic buffers.

To this aim, some typical adsorbent materials currently used in the gas separation process and in filters for water/air de-pollution (e.g., zeolites, perlite), are used in mortars as unconventional aggregates. Mortars with two different binders (cement, with and without the addition of an air-entraining admixture, hydraulic lime) and aggregates (natural sand as reference, perlite and zeolite) were manufactured and compared in terms of workability, specific weight, mechanical performances, morphological observations of the interfacial transition zone (ITZ) between binder paste and aggregate, capillary water absorption, ability to adsorb pollutants and moisture buffering ability.

2. Experimental

2.1. Materials

2.1.1. Aggregates

Natural commercial sand, ESINCALCE s.r.l., Italy, with d_{max} = 8 mm was used as reference aggregate (Fig. 1a).

As unconventional porous aggregates, perlite and zeolite were used. Perlite (Fig. 1b) is extensively used as adsorbent for heavy metals, dyes and oil removal from aqueous solutions [48]. It is widely used in cementitious materials for its lightness and thermal insulating properties [49]. Commercial perlite with d_{max} = 6 mm was used to replace the total volume of sand.

Zeolite and related micro-porous materials are among the most efficient adsorptive materials for removing VOCs [31]; they act as heterogeneous catalysts, as adsorbents and as molecular sieves in gas separation processes [31]. Commercial zeolite (Fig. 1c) with minimum Cation Exchange Capacity of 150 meq/100 was used to replace the total volume of sand.

The unconventional aggregates are more uniform sized than natural sand, as the grain size distribution in Fig. 2 shows.

The maximum diameter, measured by sieving according to UNI EN 933-1:2012; the specific surface area values, as reported by data sheets of commercial products; the densities and water

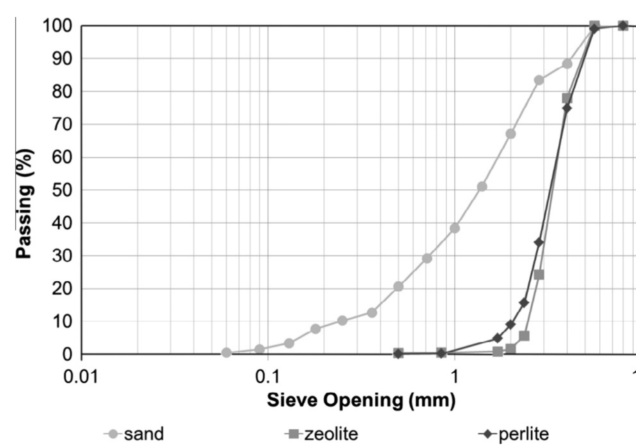

Fig. 2. Grain size distribution of aggregates.

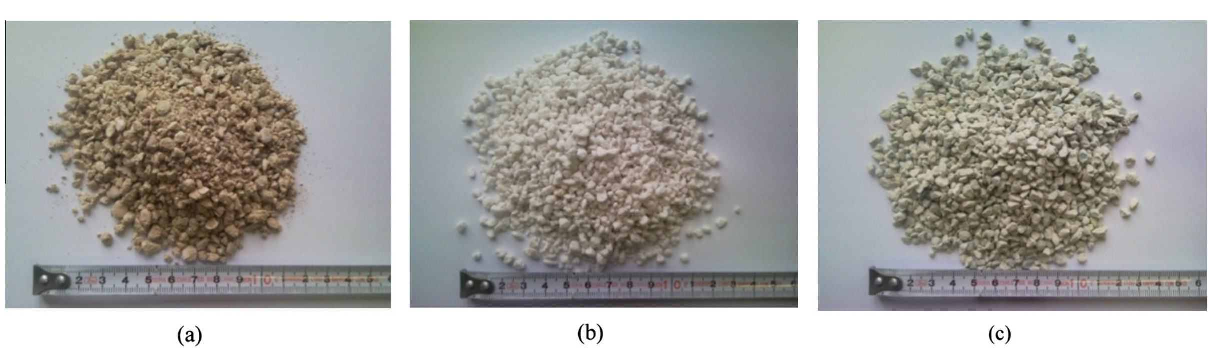

Fig. 1. Pictures of aggregates used: commercial sand (a), perlite (b), zeolite (c).