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Towards the assessment of the shear behaviour of masonry in on-site conditions: A study on dry and salt/water conditioned brick masonry triplets

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HIGHLIGHTS

- Experimental study on conditioned masonry triplets.
- Investigation on the shear behaviour of masonry triplets.
- Mechanical and material microstructural parameters are investigated.
- Damp/salts presence affects the structural behaviour of masonry.

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ABSTRACT

In this paper an experimental study conducted on fired-clay brick masonry triplets built with cement- and hydraulic lime-based mortars and subjected to artificial weathering cycles is presented. A cycle is constituted by (1) a wetting phase by capillary rise of either a saline solution or deionized water and (2) a drying phase in oven. The aim of the accelerate weathering cycles is to simulate on-site conditions of masonry structures subjected to rising damp and salts attack due to daily and seasonal microclimatic changes. For comparison purposes, triplets subjected to drying cycles only were also considered. At the end of the weathering process, the triplets were shear tested in order to quantitative assess the separate and combined effect of water and salts within the pores on the mechanical behaviour. Shear parameters were interpreted on the basis of the microstructural characteristics of the constituent materials. Particular attention was given to the pore size distribution, salt amount, and distribution within the specimens after the conditioning procedure, finding significant correlations. Results show that the triplets shear behaviour is influenced by the damp/salts presence to a different extent depending on the materials involved.

1. Introduction

Masonry buildings are affected by weathering processes due to environmental, anthropic, and physical causes. Among the environmental causes rising damp and salt attack play a significant role and become increasingly important as soils become more and more saline. Rising damp is caused by capillary suction of fine pores or voids that are present in most of masonry materials [1–6]. The capillaries rise water from the soil into the building, leading to damp zones at the walls base. Many traditional buildings were constructed on footings of dense stone which hindered the rise of water, whereas in modern constructions rising damp is prevented by the insertion of damp-proof courses (DPCs) [7], generally polymeric membranes. However, because many historical buildings were constructed without DPCs, there are usually damp problems at the walls base [8,9]. In most cases, rising damp carries soluble salts from ground.

Salt attack represents one of the most common causes of rock and stone weathering [10]. Soluble salts may derive from acid rains or marine environment [11], but they are more often associated with rising damp [12–15]. Repeated wetting and evaporation cycles due to daily/seasonal microclimatic changes lead to cyclic precipitation of salts and to the progressive decay of masonry.

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The harmful role of salt crystallization has been studied by many researchers, both experimentally [16–19] and numerically [20,21]. Under certain circumstances, soluble salts crystallize within the pores of building materials, exerting on the pore walls an additional pressure, known as crystallization pressure [22,23], which can lead to local pore disruption [24–26] and give macroscopic disaggregation effects.

Much attention has been devoted to understanding the role of salts on the physical–mechanical degradation of porous materials [17,27–30], while the effect of salts and moisture on the mechanical properties of masonry has not been widely investigated. Nevertheless, the assessment of the mechanical characteristics of masonries in their on-site conditions (possibly involving defects, decay, as well as damp and salts) is fundamental for evaluating the actual structural performance and also the vulnerability of historical buildings [31]. In particular, it is important to study, among the others, the shear behaviour of masonry, as unreinforced masonry walls often serve as shear resistant walls for the complete structure [32]. However, the issue under investigation is made complex by the high number of parameters involved, including the masonry size and internal structure, the features of bricks and mortar joints (usually extremely variable in historical masonries), the amount and height of rising damp, the nature of soluble salts, their amount and distribution, etc. In a previous paper, the authors investigated distinctly the effect of some of these parameters on the shear behaviour of brick masonry assemblies with cement-based mortars, by shear test in unconfined conditions [33]. Dry samples were compared with water saturated ones and with samples subjected to salt crystallisation cycles. The salt-rich samples were subjected to capillary rise of saline solutions (containing sulphate and chloride, respectively) in the direction parallel to the mortar joints and they were finally shear tested after drying, in order to investigate the effect of salts, sulphate and chloride separately, and the effect of water on the mechanical behaviour. Results showed that water drastically reduces shear performance of the masonry assemblies, while salt crystals, partially occluding the pores, mostly make the assemblies more brittle.

In the present paper, the influence of salt-rich rising damp on the shear behaviour of masonry is investigated by taking into account further parameters jointly acting on real buildings and hence simulating, in laboratory, conditions that may occur in practice in historical masonry constructions. To this aim, masonry triplets made of fired-clay bricks and mortar joints (both cement-based and natural hydraulic lime-based) were built and subjected to weathering cycles constituted by a wetting phase and a drying phase. The cycles aim at reproducing the on-site conditions of masonry, usually subject to daily and seasonal climatic changes. In the wetting phase, the base of the triplets was immersed in deionized water or, alternatively, in a salt-rich solution for 4 days: in such a way, capillary suction of the triplets occurred perpendicularly to the mortar joints, i.e. in the same direction experienced by masonry on-site. The saline solution was a mixture of a chloride and a sulphate, set-up to reproduce the combined effect of the most common species of salts that can be found in soils [34,35]. In the drying phase, the triplets were kept in oven at 60 °C for 3 days. As a matter of fact, the use of wet–dry cycles was found to be more realistic and effective in simulating on-site salt crystallisation than continuous immersion of the specimens in salt solution [36].

At the end of the last wetting cycle, the specimens with damp and salts within the pores, were subjected to a shear test with a pre-compression load of 1 MPa according to EN-1052-3 [37]. The triplet test is straightforward and provides reliable data for the shear strength of masonry [38]. For comparison purposes, the shear strength test was carried out also on: (i) triplets subjected to the same weathering cycles as above, but with the wetting phase in distilled water instead of saline solution and (ii) dry triplets subjected to the sole cycles in oven in order to consider the influence of the accelerated curing on mortar strength. In this way, the separate and combined actions of water imbibition and salt crystallization is quantitatively assessed. Shear behaviour parameters were interpreted in the light of the microstructural characteristics of the constituent materials. In particular, pore size distribution, amount of salts, and distribution of salt crystals within the specimen after the conditioning procedure were investigated.

2. Materials and experimental methods

2.1. Materials

The tested specimens were masonry triplets obtained by assembling three half fired-clay solid bricks with: (1) cement-based mortar (12 triplets were built, hereinafter named 'CEM') and (2) lime-based mortar (12 triplets were built, hereinafter named 'NHL'). Commercial fired-clay masonry bricks 250 mm × 120 mm × 55 mm were chosen.

For CEM mortar preparation, commercial quartz sand (<2 mm) and Portland limestone cement CEM II B 32.5 LL were mixed in a Hobart mixer (EN 196-1), with aggregate:cement:water volume ratio 3:1:1. Cement and aggregate were mixed for 120 s at speed 1, then water was added and mortar was mixed for further 120 s at speed 1 and 30 s at speed 2.

For NHL mortar preparation, natural hydraulic lime (NHL 2.5, according to EN 459-1) was mixed with the same sand, components ratio and mixing procedure of the cement type.

Three prisms of CEM and NHL mortars (40 mm × 40 mm × 160 mm, according to EN 196-1), were manufactured as well and cured for 2 months at room conditions. Three brick prisms (55 mm × 55 mm × 160 mm) were obtained from the same batch of bricks employed for manufacturing the triplets.

Mortar and brick prisms were tested for the determination of the mechanical properties.

2.2. Triplets

Each brick was cut into two halves, obtaining two 55 mm × 120 mm × 120 mm prisms. The two prisms sawn from the same brick were used one for manufacturing a CEM triplet and the other for manufacturing a NHL triplet. In this way, each cement-based triplet has a corresponding lime-based triplet, composed exactly by the same bricks, piled in the same order, as shown in Fig. 1a. In this way, the differences between a corresponding couple of triplets depend only on mortar layers, as the brick surface roughness and microstructural characteristics are exactly the same. Triplets were built by piling the brick prisms horizontally (as in real masonries), with approximately 10 mm-thick mortar layer, to achieve a realistic small scale model of masonry. Brick prisms were kept immersed in water for 48 h before the triplet construction, to assure their complete saturation and avoid the depletion of water by the mortar, possibly hindering a proper hydration. The final triplet sizes were about 185 mm × 120 mm × 120 mm, Fig. 1a. The specimens were cured for 2 months at $T = 20 \pm 5$ °C and under a polyethylene sheet to assure a complete hydration of the binder as recommended in EN 1052-3 [37].

2.3. Artificial weathering cycles

After curing, CEM and NHL triplets were subdivided into three groups. CEM and NHL specimens of the first group, hereinafter named 'CEM-SALTS' and 'NHL-SALTS', respectively, were subjected to 15 artificially weathering cycles in salts solution. Each cycle was constituted by a wetting phase and a drying phase. In the wetting phase, the triplet base was kept for 4 days immersed into 20 mm of saline solution (1 wt.% Na_2SO_4 and 1 wt.% NaCl in water), Fig. 1b, periodically refilled to assure a constant height. In the subsequent drying phase, the triplets were kept in a ventilated oven at 60 °C for 3 days.

The disposition of the specimens in Fig. 1b was chosen to reproduce the in situ condition of masonry, where bed joints are parallel to the ground and capillary rise of water and salts occurs upward. The mixture of the chloride and sulphate in the rising solution was aimed at reproducing conditions typically found in actual walls, where mixtures of different soluble salts are usually jointly present.

The number of cycles was selected on the basis of past experimental findings by the authors [33].

A second group of CEM and NHL specimens, hereinafter named 'CEM-WATER' and 'NHL-WATER', respectively, was subjected to 15 cycles identical to those above described, but distilled water was employed for the wetting phase instead of saline solution.