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Salt Attack Effects on the Shear Behavior of Masonry: Preliminary Results of an Experimental Campaign

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Abstract. In this paper, preliminary results of an experimental campaign carried out on masonry triplets subjected to weathering cycles in salt solution are presented. Weathering cycles are constituted of a wetting phase by capillary rise of a sodium chloride solution and a drying phase in oven. At the end of the last conditioning cycle, triplets are shear tested in order to quantitatively assess the effects of salts on their mechanical behaviour, in particular on the Mohr-Coulomb relationship. To this aim, three levels of pre-compression are applied during the shear tests. For comparison purposes, unconditioned triplets are also tested under the same loading conditions.

Introduction

Historic masonry buildings are affected by weathering processes due to anthropic, environmental and physical causes [1]. Among the environmental causes, salt attack plays a significant role [2]. Salts can originate from rising damp that carries soluble salts from ground to masonry basements or from acid rains or marine environment [3-5].

Repeated wetting and evaporation cycles due to seasonal microclimatic changes lead to the cyclic precipitation of salts and to the progressive degradation of masonry. Under certain circumstances, soluble salts crystallize within the pores of building materials, exerting on the pore walls an additional pressure, known as crystallization pressure [6], which can lead to local pore disruption and give macroscopic disaggregation effects that may influence the structural behaviour of the porous materials.

The role of salt crystallization on building materials has been studied by many researchers, both experimentally [7-9] and numerically [10]. Much attention has been devoted to understanding the role of salts on the physical-mechanical degradation of porous materials [11-15], while the assessment of the effects of salts on the structural properties of masonry has not been widely investigated [16,17]. In [17], an experimental campaign was conducted to investigate the effects of salts on the shear behaviour of masonry. Two types of masonry triplets subjected to different conditioning procedures were considered. Before the shear test, the triplets were subjected to cyclic wetting phases in saline solution or in water and drying phases. Results showed that the shear behavior is greatly influenced by the moisture content, porosity, mortar strength, and conditioning type. All the specimens were subjected to the same level of pre-compression load.

In the present paper, the influence of salt-rich rising damp on the shear behaviour of masonry is investigated by taking into account the behaviour of triplets under different levels of pre-compression load [18]. To this aim, masonry triplets made of fired-clay bricks and low strength cement-based mortar joints were built and subjected to weathering cycles constituted by a wetting phase and a drying phase. In the wetting phase, the base of the triplets was immersed in a sodium chloride-rich solution for four days. In the drying phase, the triplets were kept in oven at 60 ^{o}C for three days.

At the end of the last cycle, the specimens have been subjected to a shear test with different levels of pre-compression in order to determine the Mohr-Coulomb relationship [19]. In particular, the effects of the salt attack on the cohesion and static friction coefficients have been investigated. For comparison purposes, the shear strength test was carried out also on triplets left at room condition and not subjected to any type of conditioning.

Materials and Methods

Materials and Triplets. The tested specimens were masonry triplets obtained by assembling three half fired-clay solid bricks and two low strength cement-based mortar joints. Commercial fired-clay masonry bricks of nominal dimensions 250×120×55 mm^3 were chosen. Three brick prisms (55×55×160 mm^3) were obtained from the same batch of bricks employed for manufacturing the triplets. The mortar employed for the joints was a ready-mix commercial mortar M2.5 class according to EN 998-2. From the same batch of mortar used to construct the joints, three mortar prisms (40×40×160 mm^3), were manufactured and cured for 2 months at room conditions. Mortar and brick prisms were tested for the determination of the mechanical properties, such as compressive strength f_c, flexural strength f_f, and elastic modulus E (evaluated according to EN 196-1, EN 772–1, EN 1015–11 and EN 14580). Results are collected in Table 1. The final triplet sizes were about 185×120×120 mm^3. The specimens were cured for two months in laboratory conditions (T=20±5°C and RH>95%). A total of 24 triplets were manufactured.

Table 1. Mechanical properties of the materials used for the manufacturing of the specimens. Values averaged on three samples. Standard deviation within parentheses.

Material	f_c	f_f	E
u.o.m	[MPa]	[MPa]	[GPa]
Brick	16.20 (±0.02)	/	6.60 (±0.40)
Mortar	8.27 (±1.46)	2.47 (±0.41)	7.82 (±2.01)

Weathering Cycles. After curing, the triplets were subdivided into two groups, hereinafter named SALT and REF. SALT specimens were subjected to 10 artificial weathering cycles in salt 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 2 cm of saline solution (20 wt% NaCl in water) periodically refilled to assure a constant height, see Fig. 1a. In the subsequent drying phase, the triplets were kept in a ventilated oven at 60°C for 3 days. Sodium chloride has been chosen for the wetting phase being the most common salt that can be found in situ. The number of cycles was selected on the basis of past experimental findings [16,17]. SALT specimens at the end of the weathering cycles are shown in Fig. 1b. REF specimens were kept at laboratory condition (i.e. without any conditioning) for comparison’s sake.

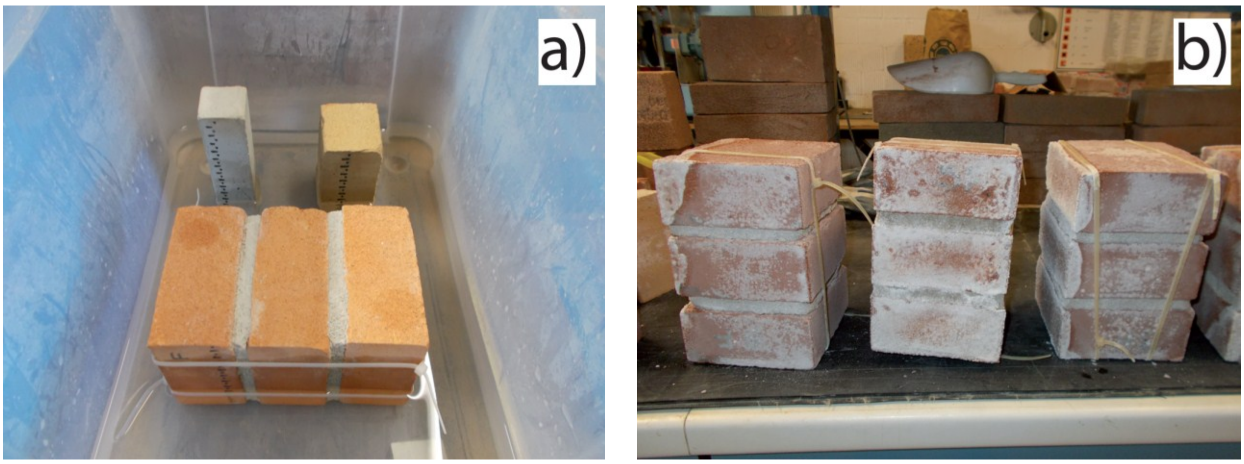


Fig. 1. Weathering cycles: a) wetting phase and b) SALT specimens at the end of the conditioning procedures.

Shear Test. The shear behavior of both REF and SALT specimens was experimentally investigated. The shear test apparatus is shown in Fig. 2. As can be noted, the configuration is similar to that proposed in EN 1052-3, where methods for determining the shear strength of masonry are described. The pre-compression load is applied by means of thick metallic plates with bores through which four threaded rods constrain uniformly the specimen. The applied compressive force was measured during the test through strain gauges glued to the rods. Two LVDTs are placed symmetrically to measure the vertical displacement (slip) of the central brick with respect the lateral ones. Before the test, the rods were tightened by a torch wrench up to the desired level of axial pre-compression. Being the determination of the shear strength the scope of the present study, the pre-compression level was set according to the Standard to three different levels: equal to 0.2, 0.6 and 1 MPa. After the application of the pre-compression load, the specimens were tested in a 100 kN Galdabini universal testing machine operating in displacement control. The shear load was applied through a hydraulic jack at a speed of 0.25 mm per minute. Displacements as well as shear and pre-compression loads were monitored through a datalogger until a 4 mm vertical displacement of the central prism occurred.

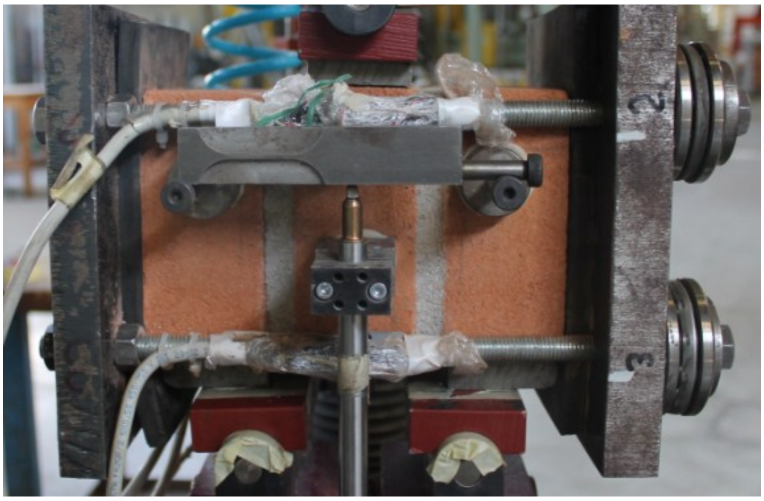
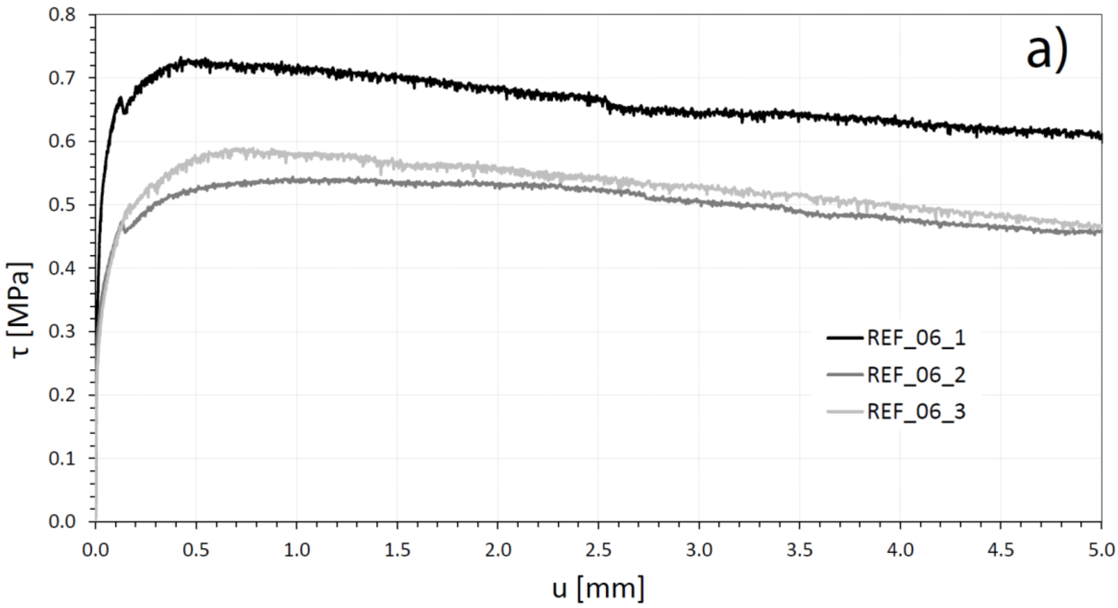


Fig. 2. Shear test of masonry triplets: experimental set-up.

Results and Discussion

Shear stress – vertical slip curves of shear tests carried out on REF and SALT specimens are collected in Figs. 3a and 3b, respectively. For the sake of brevity, only the curves related to specimens subjected to a pre-compression equal to 0.6 MPa are reported. The vertical slip u of the central prism is computed as the mean value of the displacements recorded by the two opposite LVDTs. The shear stress τ is evaluated as $\tau = S/2A$, where S is the load applied by the testing machine and A is the current area, calculated as $A = L1(L2 - u)$ being $L1$ and $L2$ the cross-section dimensions. In the following, the pre-compression stress σ is computed as $\sigma = P/A$, being P the pre-compression load applied by the four instrumented rods, calculated as the resultant of the forces applied by the rods to the specimen.



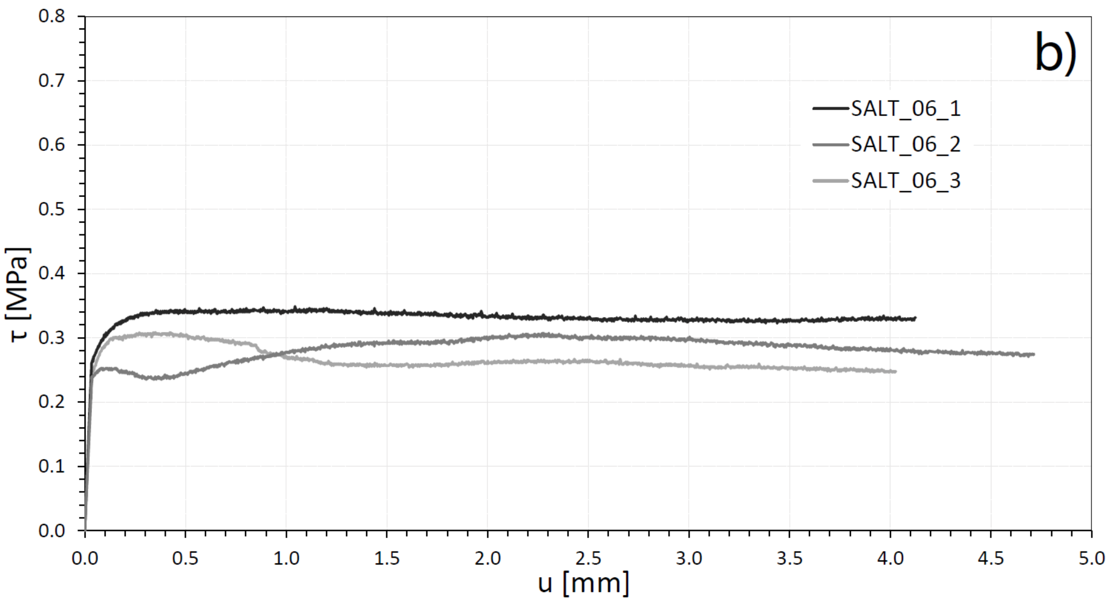


Fig. 3. Shear stress – vertical slip curves for a) REF and b) SALT specimens subjected to a pre-compression stress equal to 0.6 MPa.

Both REF and SALT curves in Fig. 3 are characterized by an almost-linear pre-peak behavior, a peak load, a post-peak softening and, in the last part, by a semi-horizontal branch. By comparing the REF curves (Fig. 3a) with the SALT ones (Fig. 3b), it appears that lower stress peaks are recorded for SALT specimens. In particular, a reduction of approximately 40% of the average stress peak is recorded in SALT specimens with respect to REF ones. After the peak load is attained, SALT specimens show a limited decrease of shear stress also for large slips (u). Therefore, the dynamic friction coefficient, which is exerted between the contact surfaces during the slipping, appears greater for aged triplets (SALT). This is due to the presence of crystallized salts which make the slipping surfaces rougher with respect to REF specimens.

By combining the outcomes of the shear tests for the three levels of pre-compression, the Mohr-Coulomb relationships for REF and SALT specimens have been evaluated. As a result, the law $\tau = 0.497\sigma + 0.284\ MPa$ has been obtained for REF specimens, whereas $\tau = 0.372\sigma + 0.159\ MPa$ has been obtained for SALT specimens. As it can be noted, a substantial decrease of the masonry shear strength is recorded for weathered specimens, showing a reduction of approximately 25% of the static friction coefficient and a reduction of approximately 44% of the cohesion value.

A picture of the failure mode for a REF specimen is reported in Figs. 4a and 4b, whereas a picture of a SALT specimen failure is shown in Fig. 4c. Although specimens of the same type presented different failure modes, in the failed mortar surfaces of SALT specimens, a concentration of salt crystallization in the external boundary systematically appeared, see Fig. 4c.

Fig. 4. a) Example of mortar joint failure for REF specimens, b) failure mode for REF and c) SALT specimens.

Conclusions

In this paper, preliminary results of an experimental investigation carried out on low strength cement-based mortar masonry triplets subjected to salt conditioning were presented. Conditioned specimens were subjected to cyclic wetting phases in saline solution and drying phases in oven, in order to artificially reproduce on-site situation typical of old masonry structures. For comparison purposes, also unconditioned triplets were considered. The conditioned masonry triplets were shear tested considering different levels of pre-compression. The Mohr-Coulomb relationships for REF and SALT specimens were evaluated. Results showed that cycles in salt solution reduce the shear strength of masonry triplets. Furthermore, cohesion and static friction coefficient values for SALT specimens were found to be substantially lower than REF ones.

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