Construction and Building Materials 82 (2015) 45–52

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Compressive behaviour of brick masonry triplets in wet and dry conditions

Elisa Franzoni [a,*], Cristina Gentilini [b], Gabriela Graziani [a], Simone Bandini [a]

[a] DICAM – Department of Civil, Chemical, Environmental and Materials Engineering, University of Bologna, via Terracini 28, 40131 Bologna, Italy
[b] DICAM – Department of Civil, Chemical, Environmental and Materials Engineering, University of Bologna, Viale Risorgimento 2, 40136 Bologna, Italy

HIGHLIGHTS

- Samples of brick, cement mortar and natural hydraulic lime mortar were manufactured.
- Their compressive behaviour in dry and saturated conditions was investigated.
- Masonry triplets (cement mortar) were tested in dry, moist and saturated conditions.
- The results were correlated with the differences between materials microstructure.

ARTICLE INFO

Article history:
Received 17 November 2014
Received in revised form 30 January 2015
Accepted 18 February 2015
Available online 6 March 2015

Keywords:
Water saturation
Compressive strength
Young's modulus
Mortar
Cement
Natural hydraulic lime
Rising damp
Historic building

ABSTRACT

Mechanical behaviour of old masonry may differ from the theoretical one to a great extent, hence it needs to be properly evaluated for quantifying the safety and serviceability of real structures, in view of their rehabilitation and/or seismic reliability assessment. Among the factors affecting such behaviour, the presence of moisture, mainly from rising damp, plays a key role in the deterioration state of old masonry structures, owing to salt crystallisation, frost damage, etc. Besides, water presence in the material pores may also directly influence their mechanical properties (compressive and tensile strength, elastic modulus), due to the interactions with the pore surface, enhancement of crack propagation velocity and other mechanisms. Although the effect of water saturation has been investigated for clay-bearing rocks, ceramics and concrete, its consequences on the mechanical behaviour of brick masonry still requires in-depth elucidation. For this reason, in the present paper the compressive strength and Young's modulus of fired-clay bricks, cement-based and lime-based mortars as well as masonry triplets are investigated, in dry and wet conditions. The results are interpreted in the light of the microstructural features of the materials, i.e., total voids amount and pores size distribution.

1. Introduction

A large part of existing buildings and architectural heritage in Europe and all over the world is made of brick, stone and earth masonry, which makes the understanding of their mechanical performance of paramount importance [1]. In particular, the vulnerability of old masonry buildings to earthquake events is a weak point which may have dramatic consequences, to an extent that seismic rehabilitation by fibre reinforced polymers (FRP) placing, reinforced injections and renders, repointing, etc. has become a major issue for research [2–6].

However, evaluating the mechanical behaviour and consequently the safety and serviceability of real masonry (not only for seismic purposes, but also for current rehabilitation works in historic buildings, often implying a change of functions) is not an easy task [7–10] and several destructive and non-destructive techniques are presently available for assessing the integrity and quality of materials in on-site masonry, aimed at providing input data for structural analysis [7,8,11,12]. Indeed, mechanical behaviour of real masonry is often far from the theoretical one, especially in historic buildings and structures, where several parameters play a key role, such as:

- extremely high heterogeneity of ancient building materials, namely brick units and stone ashlars;
- irregularity of walls;
- scarce quality of joint mortars, often manufactured with low lime content or even clay fractions;

* Corresponding author. Tel.: +39 051 2090329; fax: +39 051 2090322.
E-mail address: elisa.franzoni@unibo.it (E. Franzoni).

http://dx.doi.org/10.1016/j.conbuildmat.2015.02.052
0950-0618/

- decay of joint mortars and/or masonry units, mainly due to salt and frost damages;
- presence of moisture in porous building materials.

Among these, moisture (mainly conveyed into masonry by rising damp) is extremely frequent and several techniques are used on-site to measure its amount [13].

The contribution of moisture presence to the collapse of masonry buildings built with ferruginous stone ashlars has been highlighted in a recent paper [14], where the presence of water in the pores was found to lower both compressive strength and stiffness of the stone. In the case of ferruginous sandstone, the worse behaviour connected to saturated conditions with respect to dry ones was ascribed mainly to the presence of clay fractions, that swell due to water and hence decrease the internal friction of the stone. A static elastic modulus decrease in wet conditions was reported also in other literature papers for different kinds of clay bearing rocks and buildings stones (see, e.g., [15–20]) and several mechanisms were highlighted to play a role in decreasing the mechanical performance of saturated clay bearing stones, such as fracture energy reduction, capillary tension decrease, pore pressure increase, frictional reduction and chemical and corrosive deterioration [21]. In some cases, decreases in compressive strength and Young's modulus up to about 90% were registered for saturated clay-bearing rocks in comparison with oven dried ones [21].

A significant deterioration of the mechanical properties due to moisture presence was found also for other materials, not containing clay fractions. In the case of soda–lime–silica glass, moisture was found to increase crack growth velocity due to chemical reaction between water and the Si–O bonds in the glass [22] and, also in the case of porous ceramics (chalk and alumina), the effect of H-bonding of water in pores surfaces was highlighted [23]. For marble [24] and travertine [25], a significantly lower compressive strength in saturated conditions was registered with respect to dry state. In gypsum [26] and set plasters [27], a strong susceptibility to moisture was observed due to sliding mechanisms between gypsum crystals, amplified by water absorption [27], i.e., by the presence of 'free water' in the pores (distinguished by bound water) [23].

In most cases, the mechanical behaviour of moist materials strongly depends also on the strain rate [24,27] and confining pressure [28], decreasing for lower strain rate [24] and weaker confinement [28]. The combined effect of moisture and strain rate was specifically investigated also for concrete [29–30] and a marked reduction in compressive and flexural strength for increasing water contents was found, especially at lower displacement rates (static conditions) [29–30], while saturation seems to cause much higher strength at high strain rates and for impact loads [31]. The strain rate sensitivity of concrete strength to water was explained through different concepts, such as the 'viscous cohesive stress' of free water in the pores (e.g., [30]) or the wave propagation concept [31]. An increase in both static and dynamic elastic modulus in wet concrete was found as well [30].

Despite the high number of literature papers devoted to studying the mechanical behaviour of several porous media when water saturated, the performance of brick masonry structures in presence of rising damp, i.e., almost soaked at the base, is much less investigated and the mechanisms governing the mechanical behaviour of moist masonry are still to be completely elucidated as far as static and dynamic mechanical behaviour is concerned. While European standard EN 772-1:2011 (Methods of test for masonry units – Part 1: Determination of compressive strength) simply suggests that compressive strength of masonry units in saturated condition should be considered 20% less than oven dried units, not unequivocal results can be found in the literature.

Some authors registered a decrease in the quasi-static compressive strength of saturated brick masonry models (built with commercial solid bricks), which they attributed to the mortar, while the compressive strength of the investigated brick units alone resulted basically the same in saturated and dry conditions [32] (the relevant high-cycle fatigue strength tests gave more controversial results [32]). Conversely, in the case of ancient handmade bricks extracted from a XVI Cent. building in Venice, a drastic reduction in compressive strength was found after water-saturation with respect to dry condition, although a large results dispersion was encountered [33].

Another study on cores extracted from bricks of different types of historic masonry [34] highlighted a drop in compressive strength due to moisture, but also suggested a possible role played by pore size into such behaviour, as this effect seems more prominent in bricks with pores below 1 μm. In the case of masonry pillars, a −40% drop was registered in compressive strength in saturated condition and also a drop in stiffness, although no details were provided on the characteristics of the bricks and mortars used and the pillars size [34].

As for the shear behaviour of masonry in wet and dry conditions, to the authors' knowledge, studies are even less numerous [8,35–36] and suggest that saturation causes a deterioration in strength (up to one half) and stiffness.

The aim of the present paper is providing a contribution towards a better knowledge of the mechanical behaviour of brick masonry in presence of water. Specimens of single materials (brick, cement-based mortar and natural hydraulic lime mortar) and masonry triplets (with cement-based mortar) were tested in wet and dry conditions, interpreting the compressive strength and Young's modulus data in the light of the different microstructural characteristics of the materials considered. As a matter of fact, masonry is a complex system where several parameters contribute to the behaviour of the whole (nature of the components, geometry and size of the components, interface, etc.): highlighting the behaviour of materials separately and jointly may help to better understand not only the role played by water on the mechanical behaviour of brickworks, but also the mechanisms governing such behaviour. Of course, as real masonry walls are extremely heterogeneous and variable, depending on their age and geographical location, the data provided in the paper are not meant to address all the possible sides of the investigated subject.

2. Materials and methods

2.1. Materials and specimens

Commercial solid fired-clay bricks having size 55 × 120 × 250 mm^3 were used for the tests. From each brick, two prismatic samples 50 × 50 × 160 mm^3 were cut, for performing compressive strength test and measuring the Young's modulus, Fig. 1.

For the manufacturing of the mortars, two kinds of binder were selected: Portland limestone cement, CEM (CEM II B-LL 32.5 R, according to EN 197-1 [37]), and natural hydraulic lime, NHL (NHL 3.5, according to EN 459-1 [38]). Quartz sand with maximum grain size 2 mm was used as aggregate. Mortars were prepared in a Hobart mixer with a 3:1:1 aggregate:binder:water ratio by bulk volume, according to the mixing procedure in EN 196-1 [39]. This volume ratio reflects the proportions currently used for bedding mortars in buildings and corresponds to the following aggregate:binder:water weight ratios: 3.79:1:0.82 for CEM mortar and 3.79:1:0.88 for NHL mortar. Six 40 × 40 × 160 mm^3 prismatic samples were cast for each kind of mortar and they were used for the tests in dry and wet conditions. CEM mortar samples were left to cure for 2 months at $T = 20 \pm 2$ °C and RH ⩾ 90%, while NHL mortar samples were left to cure over one month at $T = 20 \pm 2$ °C and RH ⩾ 90% and following two months in laboratory conditions at $T = 20 \pm 2$ °C, RH = 50 ± 5%. Three months were considered necessary for the curing of this latter mortar in order to allow for its hardening, especially considering the long time required for carbonation (and also for achieving complete hydration reactions, although a major part of these is expected to have taken place in the first month at high relative humidity).