Performance Characteristics Evaluation of Current and Environmental-based Solutions of Infill Masonry Walls of Reinforced Concrete Buildings - Assessment of Mechanical and Hygrothermal Characteristics

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Abstract: - The evaluation of the building´s performance, particularly concerning its hygro-thermo-mechanical behavior, entails that external environmental actions should be considered together with the mechanical loads acting in the building, aiming for a realistic behavior analysis. That adequate analysis could contribute to the improvement of the patterns of safety and comfort of the buildings, which meet the increased social demand for their upgrade, as well as to minimize the anomalies in their envelope, such as cracking and water penetration. Therefore, innovative solutions have been used progressively, in the last decades, for the construction of unreinforced masonry (URM) infill walls of the envelope of buildings with reinforced concrete structure (RCS buildings), particularly to enhance their capacity to face the normal subjected mechanical loads and hygrothermal actions, mainly those related with temperature and moisture variations. Moreover, ultimately, the crescent concern about environmental issues in building construction, especially related to climate changes, has led to an intense search for new construction solutions of unreinforced masonry (URM) infill walls in their envelope, which could, particularly, reduce the environmental impact of the building and increase their energy efficiency, while assuring adequate levels of indoor comfort and durability of the buildings. The aim here is to analyze the hygro-thermo-mechanical behavior of URM infill walls, particularly evaluating the basic performance characteristics of current and environmental-based solutions of masonry walls of buildings. Initially, basic elements about masonry wall characteristics are described, particularly referring to the main types of masonry units and mortar joints, with a description of the current and environmental-based solutions mainly based on masonry units made with bio-based and waste materials. Subsequently, a general description of the relevant performance requirements of these types of URM infill walls is presented. Finally, relevant mechanical and hygrothermal properties of particular types of masonry units are assessed.

Key-Words: - Infill masonry, walls, Performance characteristics, Buildings, Environmental actions, Service life.

Received: July 19, 2024. Revised: November 27, 2024. Accepted: December 21, 2024. Published: December 31, 2024.

1 Introduction

The evaluation of the building´s performance, particularly concerning its hygro-thermo-mechanical behavior, entails that external environmental actions should be considered together with the mechanical loads acting in the building [1], aiming for a realistic behavior analysis. That adequate analysis could contribute to the improvement of the patterns of safety and comfort of the buildings, which meet the increased social demand for their upgrade, as well as to minimize the anomalies in their envelope, such as cracking and water penetration. Therefore, innovative solutions have been used progressively, in the last decades, for the construction of unreinforced masonry (URM) infill walls of the envelope of buildings with reinforced concrete structure (RCS buildings), particularly to enhance their capacity to face the normal subjected mechanical loads and hygrothermal actions, mainly those related with temperature and moisture variations. Moreover, ultimately, the crescent concern about environmental issues in building construction, especially related to climate changes [1], [2], has led to an intense search for new construction solutions of unreinforced masonry (URM) infill walls in their envelope, which could, particularly, reduce the environmental impact of the building and increase their energy efficiency, while assuring adequate levels of indoor comfort and durability of the buildings.

The aim here is to analyze the hygro-thermo-mechanical behavior of URM infill walls, particularly evaluating the basic performance characteristics of current and environmental-based solutions of masonry walls of buildings, with a particular focus on the assessment of mechanical and hygrothermal properties of some type of masonry units. Initially, basic elements about masonry wall characteristics are described, particularly referring to the main types of masonry units and mortar joints, with a description of the current and environmental-based solutions mainly based on masonry units made with bio-based and waste materials. Subsequently, a general description of the relevant performance requirements of these types of URM infill walls is presented, particularly depicting the main performance characteristics of masonry units and the specific performance characteristics of URM infill walls made of masonry units made with waste materials. Finally, relevant mechanical and hygrothermal properties of particular types of masonry units are assessed.

2 Need for Improved Knowledge about the Innovative and Environmental-Based Solutions of Infill Masonry Walls and the Methodology of the Present Study

The performance of the RCS building envelope could be significantly affected by the current external environmental conditions, [1], mainly associated with normal actions of temperature, rain, and wind, as well as related to climate changes.

Loads applied to the building envelope can lead to deformations, which could lead to cracking of masonry walls and confining construction elements of the building´s envelope, particularly due to vertical loads of the structural elements that support the walls, [3]. Cracking of URM infill walls masonry of building envelope could also be caused by deformations of URM infill walls and confining structural elements due to temperature and moisture variations, [1].

Furthermore, solutions for the construction of unreinforced masonry (URM) infill walls of the envelope of buildings with reinforced concrete structure (RCS buildings), should particularly address these adverse loads and environmental conditions and aim to improve their ability to resist adequately the subjected mechanical loads and hygrothermal actions, especially those that are forecast in the future associated to climate changes. Moreover, the knowledge of the characteristics of the URM infill walls and the respective technique of construction is essential to analyze the deficiencies in the performance behavior that could occur in the RCS building envelope.

Aiming to upgrade the energy efficiency of a building´s envelope, could lead to the choice of increasing the role of construction materials in the environmental impact of the building, and could mean, in a global footprint, an essential influence factor. In this path, the search for alternative materials and the development of new technologies to improve the sustainability of construction practices could be an interesting and useful option.

Thus, the main motivation behind this work is to study the hygro-thermo-mechanical behavior of URM infill walls, with a particular focus on the assessment of mechanical and hygrothermal performance characteristics of current and environmental-based solutions of infill masonry walls of buildings, especially their mechanical and hygrothermal characteristics.

Considering the referred need for improved knowledge on the performance characteristics of innovative and environmental-based solutions of infill masonry walls of buildings, the methodology of the present study will consist of the evaluation of the basic performance characteristics of the referred solutions of masonry walls of buildings. Initially, basic elements about masonry wall characteristics are described, particularly referring to the main types of masonry units and mortar joints, with a description of the current and environmental-based solutions mainly based on masonry units made with bio-based and waste materials. Subsequently, a general description of relevant performance requirements of these types of URM infill walls is presented, particularly related to the following issues: main performance characteristics of masonry units; example of determination of dimensional and mechanical characteristics of a type of innovative vertically perforated ceramic block; basic performance characteristics of the masonry walls; specific performance characteristic of URM infill walls made of masonry units made with waste materials. Finally, the assessment of relevant mechanical and hygrothermal properties of relevant types of masonry units is made, particularly related to the following issues: dimensional and physical properties of the masonry units; mechanical characteristics; hygrothermal characteristics of the masonry units; global analyses of the results.

3 Basic Elements of Masonry Walls Characteristics

A masonry wall is a composite material made with masonry units, such as bricks, stones, or concrete blocks, which construction technique involves stacking these masonry units and joining them in different bonding, particularly using mortar (mortar joints), grout, surface bonding or some combination of these methods. These masonry units are usually linked with mortar in their bed mortar joints and in their head mortar joints. The bed mortar joint consists of a horizontal layer of mortar between masonry units, while the head mortar joint consists of a vertical mortar joint placed between masonry units. Generally, the wall section could correspond to a single leaf or two leaves of different thicknesses, which can be connected or separated by an internal layer, filled with insulation material, or not filled at all (void space).

3.1 Main Characteristics of Masonry Walls

Masonry is considered a non-homogeneous material and could exhibit different mechanical properties, due to the diverse types of masonry units and mortar used; therefore, the masonry elements could present distinct mechanical behavior according to their type of constituents.

The main types of masonry walls differ between them in their loadbearing characteristics and arrangement of the constituent materials and the following could be highlighted: load-bearing masonry wall; reinforced masonry wall; hollow/cavity masonry wall; composite masonry wall; post-tensioned masonry wall. In composite masonry walls, two wythes of masonry units are constructed by bonding both wythes and combining two or more building materials, for example: one wythe can be bricks and the other stones and bricks; or one wythe can be stone, while the other can be concrete blocks.

Reinforced masonry is a type of combined construction where the masonry units are subjected to compressive pressure and the inner support is subjected to flexible pressure and usually are load-bearing walls.

3.2 Specific Characteristics of Masonry Walls Related to Hygrothermal Properties

Construction materials, such as masonry units, expand or contract when their temperature changes, with expansion or contraction occurring in all directions. Materials that expand at the same rate in every direction are referred to as isotropic materials, and for example, some types of solid brick units can be considered isotropic materials. Regarding thermal material properties of masonry walls, one of the most relevant is the ratio between the relative expansion (or strain) and the change in temperature in a masonry wall, which is usually designated as the coefficient of thermal expansion (thermal expansion is here considered as the tendency of a material to change its shape, area, and volume in response to a change in temperature).

Moreover, the heat capacity of a porous material, such as the case of solid masonry units, is related to its moisture content. The moisture dependence on the thermal conductivity of a wet solid masonry unit, usually, could be assumed as a linear relationship, established on experimental values determined for different moisture content conditions.

4 Main Types of Masonry Units and Mortar Joints for Masonry Walls

The traditional masonry units used in the past were based on natural stone and fired clay bricks, and brickwork and stone masonry walls are the oldest forms of masonry construction. Brickwork is constructed with the arrangement of clay bricks in courses, bonding them with mortar. Two types of stones can be used to create stone masonry walls: dressed or undressed masonry walls.

Recently environmental-based solutions of masonry walls were used, especially regarding solutions of URM infill walls based on masonry units made with bio-based and waste materials [4], [5] and [6].

4.1 Current Types of Masonry Units

Innovative solutions were used progressively, in the last decades, for the construction of unreinforced masonry (URM) infill walls of the envelope of buildings with reinforced concrete structure (RCS buildings). The most common of these types of masonry units are made from normal and lightweight concrete, calcium silicate, natural stone, and fired clay.

The main materials used in the manufacture of brick are adequate clay, sand, and water, which should be mixed with small amounts of water, to develop suitable strength upon drying and when burned, as well as durable characteristics. Recently, the type of recycled clay masonry bricks derived from the de-installation of clay masonry construction blocks had a crescent use.

Current bricks could be of the following different types:

- Sun-dried bricks (these are made by molding wet clay mixed with straw or other fibers and then allowing them to dry in the sun);
- Burnt clay bricks;
- Concrete bricks;
- Engineering bricks;
- Calcium silicate bricks;
- Fly ash bricks;
- Eco bricks.

Concrete masonry units (CMUs) are commonly precast rectangular blocks (prisms) in various sizes and shapes and specialized shapes manufactured from pressed, cast, or extruded aggregate concrete. The concrete mix, consisting mainly of cement and pozzolan, water, additives, and fine and coarse aggregates (such as limestone), is usually mixed in an automated mixer previously their transportation to the block-making machine. CMUs are used for the construction of non-loadbearing and load-bearing walls. CMUs cast in special forms can assume various appearances: fluted, ribbed, or rough-textured. Solid Concrete is used for internal load-bearing walls and in the form of a cavity wall. The CMUs should present, when they reach the hardened state, adequate strength, and durability characteristics.

To decrease the use of Portland cement, which contributes significantly to the emission of greenhouse gas, the use of high content of pozzolanic industrial by-products is a possible alternative, through the replacement of part of the Portland cement, which could possibly increase the durability of CMUs. Lightweight concrete (lightweight aggregates and autoclaved aerated concrete) blocks (density range of 1000–1500 kg/m^3) are also broadly used for a diversity of construction forms.

4.2 Solutions of URM Infill Walls based on Masonry Units made with Bio-Based Materials

To improve the sustainability of construction practices, alternative materials are used and the development of new technologies is in course, particularly regarding the use of bio-based for the building construction sector. Bio-based building materials could be used to create environmental solutions, aiming to contribute to storing carbon during the service life of the building. Some examples of common bio-based materials, which can be used straight as bulk raw material or in a large diversity of processed forms (fiber, panel, bio-aggregate concrete, etc.), are wood, flax, straw, hemp, cork, bamboo, rattan, reeds, clay, and earth.

4.3 Solutions of URM Infill Walls based on Masonry Units made with Waste Materials

Agro-industrial wastes are classified into agricultural residues and industrial residues. The industrial waste materials commonly used for the production of concrete for multiple purposes (roads, blocks/bricks for construction of buildings, etc.) are Fly Ash (FA), blast furnace slag, silica fume, rice husk ash, Palm Oil fuel ash, and waste glass.

The three main methods for producing bricks from waste materials are the following: firing, cementing, and geopolymerization. The use of bricks from waste materials for the construction industry is still very limited. Geopolymer is considered an alumina-silicate material to replace Ordinary Portland cement OPC.

Geopolymer masonry units (bricks and compressed blocks (GMU)), can be produced from different types of wastes such as fly ash (FA), blast furnace slag (FS), Mine tailings (MT), and Metakaolin (MK). The alkali activator type and the curing temperature are two major factors that determine the behavior of GMU. Geopolymer blocks are sustainable alternatives to conventional bricks made from fly ash cured at room temperatures, [6].

Fly ash (FA) is one of the major potential waste materials for the production of GMU due to its amorphous structure and fine particle size which yield high reactivity for geopolymerization, [6]. The use of fly ash as a lightweight aggregate (LWA) could aim the recycle waste, with possible profits, in economic and environmental terms, if used as an LWA.

Furnace Slag (FS) is a product of mining operations generated from the smelting or fire refining processes. It has been used as construction bricks. FS can be used alone or mixed with other wastes such as MT to produce GMU, [6].

Mine tailings (MT) are waste materials made from mineral processing operations and consisting of fine particles based essentially on silica and alumina minerals and suitable for geopolymerization, [6].

Metakaolin (MK) is an adequate reactive material for the geopolymerization process, due to its highly amorphous structure. While MK is advantageous in comparison with different types of waste materials for geopolymer production, it is generated from clay which has to be produced through high-temperature heating, [6].

GMU could likewise be produced from waste concrete resulting from the demolition of old concrete structures.

5 General Description of Relevant Performance Requirements of URM Infill Walls

In the following a general description of relevant performance requirements of URM infill walls is made, particularly presenting the basic performance characteristics of masonry units and of the correspondent masonry walls, including specific performance characteristics of URM infill walls made of masonry units made with waste materials.

It is important that the construction sector improve its cost-effectiveness, quality, energy efficiency, and environmental performance and reduce the use of non-renewable resources.

The advantages of concrete blocks include durability and cost. Stone masonry generally has appreciable resistance and durability and is a weather-resistant construction material. CMUs represent a low environmental impact construction system.

Aiming the competitiveness of bio-based and waste materials it is expected that they could progressively offer controlled durability with reduced life cycle costs and maintenance as well as adequate service life.

5.1 Main Performance Characteristics of Masonry Units

Some of these innovative types of masonry units developed in the last decades were widely used and their characteristics become sufficiently uniform to allow them to be covered by international standards namely those types of masonry units made from normal and lightweight concrete, calcium silicate, natural stone, and fired clay. The European specifications for masonry units consisted essentially of the following CEN norms: EN 771-1 (Clay masonry units), [7]; EN 771-2 (Calcium silicate masonry units), [8]; EN 771-3 (Aggregate concrete masonry units (Dense and lightweight aggregates)), [9]; EN 771-4 (Autoclaved aerated concrete masonry units), [10]; EN 771-5 (Manufactured stone masonry units, [11]; EN 771-6 (Natural stone masonry units), [12].

According to the referred CEN norms, the requirements for these masonry units are generally the following:

- Dimensions and tolerances
- Configuration and appearance
- Density (gross dry density of the units; net dry density of the concrete, if applicable)
- Mechanical strength (compressive strength; bending tensile strength)
- Thermal properties
- Durability
- Water absorption by capillarity (when applicable)
- Active soluble salts content (if applicable)
- Moisture movement
- Water vapor permeability
- Reaction to fire
- Shear bond strength (if applicable)
- Bond strength (if applicable)

The Methods of testing for masonry units are the following:

- EN 772-1:2011+A1:2015, Part 1: Determination of compressive strength, [13];
- EN 772-2:1998 /A:2005, Part 2: Determination of percentage area of voids in aggregate concrete masonry units (by paper indentation), [14];
- EN 772-3:1998, Part 3: Determination of net volume and percentage of voids of clay masonry units by hydrostatic weighing, [15];
- EN 772-4:2001, Part 4: Determination of real and bulk density and of total and open porosity for natural stone masonry units, [16];
- EN 772-7:1998, Part 7: Determination of water absorption of clay masonry damp proof course units by boiling in water, [17];
- EN 772-9:1998 /A1:2005, Part 9: Determination of volume and percentage of voids and net volume of clay and calcium silicate masonry units by sand filling, [18];
- EN 772-11:2011, Part 11: Determination of water absorption of aggregate concrete, manufactured stone, and natural stone

masonry units due to capillary action and the initial rate of water absorption of clay masonry units, [19].
- EN 772-13:2000, Methods of test for masonry units - Part 13: Determination of net and gross dry density of masonry units (except for natural stone), [20].
- EN 772-14:2002 - Methods of test for masonry units - Part 14: Determination of moisture movement of aggregate concrete and manufactured stone masonry units, [21];
- EN 772-16:2011, Methods of test for masonry units - Part 16: Determination of dimensions, [22];
- EN 772-19:2000, Methods of test for masonry units — Part 19: Determination of moisture expansion of large horizontally perforated clay masonry units, [23];
- EN 772-20:2011+A1:2005, Methods of test for masonry units - Part 20: Determination of flatness of faces of masonry units, [24];
- EN 772-21:2011, Methods of test for masonry units - Part 21: Determination of Water Absorption of Clay and Calcium Silicate Masonry Units by Cold Water Absorption, [25];
- EN 772-22: 2018, Methods of test for masonry units - Part 22: Determination of freeze/thaw resistance of clay masonry units, [26];
- EN 1052-1:1998, Methods of test for masonry- Part 1: Determination of compressive strength, [27];
- EN 1052-3:2002/A1:2007, Methods of test for masonry - Part 3: Determination of initial shear strength, [28].

5.2 Example of Determination of Dimensional and Mechanical Characteristics of a Type of Innovative Vertically Perforated Ceramic Block

An example is presented of the determination of performance characteristics of a type of masonry unit, particularly of dimensional and mechanical characteristics of a type of innovative vertically perforated ceramic block (Figure 1).

Fig. 1: Top view of the vertically perforated ceramic block, [1]

a) dimensional characteristics

The determination of external dimensions of the individual specimens of the sample of ten ceramic blocks (Figure 2) is here based on the European norm EN 772-16, Methods of test for masonry units — Part 16: Determination of dimensions, [22], and their results are presented in Table 1.

Table 1. External dimensions of the individual specimens of the sample of the bricks

Masonry unit (Block)	External dimensions		
	Length [(1)] l_u	Width [(2)] w_u	Height [(3)] h_u
M1	295.6	137.3	193.2
M2	298.7	137.4	193.5
M3	295.4	136.8	193.5
M4	296.6	137.3	191.0
M5	296.5	137.6	193.0
M6	295.5	136.8	193.0
M7	295.6	136.4	190.8
M8	295.5	137.0	192.8
M9	297.0	137.2	193.0
M10	298.3	138.0	193.0
Mean	**296.4**	**137.2**	**192.7**

(1) – lu is the length of the masonry unit defined by its intended orientation in use, (mm)
(2) – wu is the width of the masonry unit defined by its intended orientation in use, (mm)
(3) – hu is the height of the masonry unit defined by its intended orientation in use, (mm)

The measurements of external dimensions and thickness of webs in vertically perforated ceramic blocks vertically perforated ceramic blocks, revealed average dimensions of approximately 296 mm (length) x 137 mm (thickness) x 193 mm (height).

The thickness of webs/shells and combined thickness of webs and shells of the sample of ten ceramic blocks are here determined based on the norm EN 772-16, Methods of test for masonry units — Part 16: Determination of dimensions, [22], and their results are presented in Table 2.

Table 2. The thickness of webs/shells and the combined thickness of webs and shells

The thickness of webs and of shell and the combined thickness of webs and shells (mm)				
	Transversals		Longitudinals	
1	Individual [1] $t_{e1};t_{i2};t_{i3};t_{i4};t_{i5};$ $t_{i8};t_{i9};t_{i10};t_{i11};t_{e12}$	Comb [2]	Individual [1] $l_{e1};l_{i3};l_{i5}:l_{e7}$	Comb [2]
2	9.9; 9.3;4.4; 8.7; 10.0; 13.7; 5.6; 8.8; 9.2; 10.9	90.5	12.1; 4.8; 3.9; 11.2	32.0
3	12.8; 8.4; 8.2; 5.7; 12.2; 9.4; 6.9; 6.4; 7.9; 14.8	92.7	12.3; 3.7; 4.2; 12.5	32.7
4	11.1; 9.1; 8.6; 5.1; 13.8; 10.0; 8.8; 4.4; 9.4; 10.5	90.8	12.0; 4.4; 3.8; 11.5	31.7
5	10.5; 9.7; 4.5; 8.7; 10.2; 13.7; 5.5; 8.7; 8.9; 11.2	91.6	12.4; 4.3; 4.1; 11.1	31.9
6	11.3; 8.8; 9.3; 5.5; 13.8; 9.8; 8.7; 4.0; 9.5; 9.8	90.5	11.9; 4.5; 3.4; 11.4	31.2
7	10.8; 8.8; 9.3; 5.4; 14.1; 10.3; 8.9; 4.4; 9.3; 9.4	90.7	12.2; 4.6; 3.5; 11.2	31.5
8	9.4; 9.0; 4.3; 8.4; 10.3; 14.0; 5.4; 9.0; 8.7; 10.7	89.2	12.0; 4.5; 3.7; 11.3	31.5
9	11.4; 7.0; 6.2; 6.8; 10.2; 13.4; 5.6; 9.3; 8.5; 11.3	89.7	11.1; 3.8; 4.5; 12.2	31.6
10	10.5; 9.3; 4.4; 8.7; 10.2; 13.6; 5.2; 8.7; 8.8; 11.0	90.4	12.1; 4.2; 3.8; 11.2	31.3
	12.0; 10.5; 4.6; 8.8; 9.6; 12.8; 6.3; 7.9; 8.9; 12.2	93.6	12.7; 4.2; 3.9; 12.1	32.9
	Mean	**91.0**	-	**31.8**

1 - thickness of webs; thickness of shells;
2 - combined thickness of webs and shells

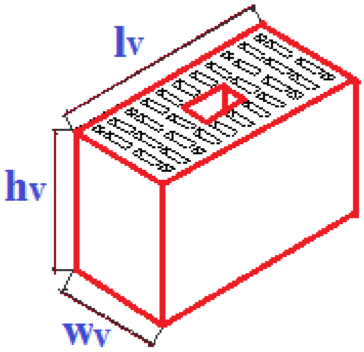


Fig. 2: Schematic view of the vertically perforated ceramic block, [1]

The determination of volume and percentage of voids and net volume is made based on EN 772-9, Methods of test for masonry units — Part 9: Determination of volume and percentage of voids and net volume of clay and calcium silicate masonry units by sand filling, [18], and their results are presented in Table 3.

Table 3. Volume and percentage of voids and net volume

Nº of the block	Volume of voids $V_{s,u}$ (mm^3)	Apparent volume $V_{g,u}$ (mm^3)	Percentage of voids $\frac{V_{s,u}}{V_{g,u}}x100$ (%)
1	$402x10^4$	$782x10^4$	51
2	$392x10^4$	$790x10^4$	50
3	$400x10^4$	$785x10^4$	51
4	$394x10^4$	$773x10^4$	51
5	$403x10^4$	$787x10^4$	51
6	$401x10^4$	$781x10^4$	51
7	$398x10^4$	$769x10^4$	52
8	$403x10^4$	$785x10^4$	51
9	$395x10^4$	$788x10^4$	50
10	$396x10^4$	$793x10^4$	50
Mean			**51**

b) Mechanical characteristics (compressive strength of masonry units)

The determination of the compressive strength of the masonry units is made based on EN 772-1, [13].

The compressive strength of the individual specimens and mean compressive strength of the sample (mean value of the strength of the individual specimens) of the ceramic blocks are determined based on the norm EN 772-1:2011+A1:2015 - Methods of test for masonry units - Part 1: Determination of compressive strength, [13] and their results are presented in Table 4.

The strength of each specimen was obtained by dividing the maximum load achieved by its loaded area, which is the gross area for units intended to be laid on a full bed of mortar. The compressive strength was calculated as the mean value of the strength of the individual specimens to the nearest 0.1 N/mm^2. The coefficient of variation of the sample is 10.7. The compressive strength of the sample of blocks, in

N/mm^2, to the nearest 0.1 N/mm^2, is 21.4 (N/mm^2). The aspects of the different phases of the compression test are in the following presented (Figure 3, Figure 4, Figure 5, and Figure 6).

Table 4. Compressive strength of the individual specimens and mean compressive strength of the sample (mean value of the strength of the individual specimens) of the ceramic block

Nº of the block	Gross area (mm^2)	Maximum load F (N)	Compressive strength (N/mm^2)
1	40484	1143000	28.2
2	41030	896600	21.9
3	40582	1129000	27.8
4	40536	1071000	26.4
5	40725	858400	21.1
6	40556	879900	21.7
7	40365	995200	24.7
8	40522	998900	24.7
9	40662	1115000	27.4
10	41037	973300	23.7
Mean			**24.8**

Gross área: (l_u x w_u)
Compressive strength: F/(l_u x w_u)

Fig. 2: Aspect of the intermediate phase of the compression test

Fig. 3: Another aspect of the intermediate phase of the compression test

Fig. 4: Aspect of the final phase of the compression test

Fig. 5: Another aspect of the final phase of the compression test

5.3 Basic Performance Characteristics of the Masonry Walls

The basic performance characteristics of the masonry walls could be related to the verification the basic requirements, as stated European Standardization (Regulation (UE) n.º 305/2011, 9 of Mars of 2011. PT 4.4.2011, JOCE L 88/33): BWR1-Mechanical resistance and stability; BWR2-Safety in case of fire; BWR3-Hygiene, health and environment; BWR4-Safety and accessibility in use; BWR5-Protection against noise; BWR6-Energy economy and heat retention; BWR7-Sustainable use of natural resources). These basic requirements are presented in the following.

5.3.1 Mechanical Resistance and Stability (BWR1)

The tests for determination of masonry mechanical resistance could be based on the following CEN norms: EN 1052-1:2002, Methods of test for masonry- Part 1: Determination of compressive strength, [27]; EN 1052-3:2002, Methods of test for masonry - Part 3: Determination of initial shear strength, [28]. The procedure is described in EN 1996-1-1+A1:2013, Clause 3.6.1.2 (1) (i) and the masonry units and mortar types are relevant for the determination of masonry wall mechanical performance.

5.3.2 Safety in Case of Fire (BWR2)

Fire reaction and fire resistance are important issues in these basic requirements and are referred to in the following.

1) Fire reaction
Classes of Fire reaction of masonry units could be based on the system of classification of EN 13501-1. To classify the masonry walls fire reaction, the wall could be subjected to the SBI test and to ignitability test.
2) Fire resistance
The external masonry walls classification system could be based on EN 1365-1 Fire resistance tests for loadbearing elements – Part 1: Walls. The characterization in terms of fire resistance of the external render of the masonry wall of the building façade could be based on the classification system of EN 13501-2+A1 "Fire classification of construction products and building elements - Part 2: Classification using test data from resistance fire tests, excluding ventilation services".
3) Hygiene, health, and the environment (BWR3)
In this basic requirement, is relevant the impact on the environmental quality of the building, particularly during their use, of the release of dangerous substances and emissions of hazardous particles into the air inside or outside of the building; and moisture in parts or construction work surfaces. Water leakage to the interior is to be minimized through the absorption of water leaked and progressive expel of it as vapor. Water that penetrates cavity wall systems in the facade of the building should be conveyed to internal through-wall flashings and weep holes via wall cavities.

   The presence of moisture inside the walls of the building could lead to the formation of moisture and mold stains in the renders with their progressive degradation, especially in interior finishes. The water absorption by partial immersion of the masonry units (long term could be assessed following EN ISO 16535, Method B; and the water absorption by capillarity of the bed faces of the masonry units could be assessed following EN 772-11. Also important is the assessment of water vapor resistance of the walls and the release of dangerous substances.
4) Safety and accessibility in use (BWR4)
Permanent and accidental loads acting on interior and exterior walls are relevant for this requirement, especially accidental actions of shock resulting from falling or projection of people and objects, or eccentric loads associated with the suspension of equipment in internal masonry walls, The resistance to the impact of masonry walls is important, and the respective tests could be based on EOTA document "Technical Report TR 001: 2003 – Determination of impact resistance of panels and panels assemblies", and the appreciation of the results could be based on EOTA guideline ETAG 003:2008 "Internal partition kits for use as non-loadbearing walls" (6.4 do ETAG 003).
5) Protection against noise (BWR5)
The sound insulation of a masonry wall of facade buildings element can be determined by the estimation of the airborne sound insulation index $D_{2m,nT,w,}$ and the airborne sound insulation, $D_{nT,w}$ for internal masonry walls of the building and the respective tests could be based on the EN ISO 10140-2:2010.
6) Energy economy and heat retention (BWR6)
Thermal insulation of the envelope is a key factor for the reduction of energy consumption the improvement of thermal comfort and avoid surface condensation and mold growth. The thermal resistance of the masonry walls is important to be assessed, and particularly the thermal conductivity of the masonry unit is an important parameter.
7) Sustainable use of natural resources
In this basic requirement it is important to assess the sustainable use of natural resources and, in particular, the re-use or recyclability of the masonry construction; and the durability characteristics of the masonry walls.

5.4 Specific Performance Characteristics of URM Infill Walls made of Masonry Units made with Bio-Based Materials

The performance of bio-based materials could mean interesting benefits in the modern construction of masonry walls of buildings, [4], [5]. These materials contain biomass and could hence store carbon during the service life of the construction. Bio-based materials compared to standard materials, generally, require less embodied energy. Therefore, the use of bio-based raw materials could help to increase the performance requirement (sustainable use of natural resources), and possibly expect to offer conditions of recyclability.

Generally, bio-based materials could have interesting insulating and hygroscopic properties, which could contribute to enhancing the thermal and indoor comfort of the building, especially for variations of relative humidity, through their ability to absorb and desorb humidity in the air, preventing extreme values of humidity and helping to maintain indoor comfort.

5.5 Specific Performance Characteristics of URM Infill Walls made of Masonry Units made with Waste Materials

The use of GMU for masonry cold possibly promotes sustainability, through the conservation of natural source material associated with the use of waste material and dropping energy usage due to low- low-temperature curing, and could expected to enhance the mechanical characteristics and durability of concrete, [6].

6 Assessment of Relevant Mechanical and Hygrothermal Properties of Particular Types of Masonry Units

Buildings exposed to daily and seasonal climatic changes, particularly, to the air temperature and solar radiation (thermal actions), could result in significant variations of the temperature distribution within individual elements of these buildings. Thermal actions corresponding to air temperature and solar radiation on building elements are those actions that arise from the changes of temperature fields within a specified time interval, [29] (EN 1991-1-5/A1:2005/AC:2010; 1.5.1 Thermal actions). These thermal actions are assumed as variable and indirect actions, [30] (EN 1990:2002, 1.5.3 and 4.1.1).

Regarding the moisture variations related to rainwater penetration in the RCS building envelope, actions from rainwater on the building envelope could be relevant and account for the conditions where a gathering of water occurs. These actions caused by water may be taken into account as permanent or variable actions according to the specific environmental conditions and could be represented as static pressures and/or hydrodynamic effects (in case, for example, of hydrodynamic force due to currents of water (inundations) on immersed parts of the building, [29].

The hygienic properties of porous building materials are essential information for the assessment of moisture-related processes, [1]. Therefore, to help the analysis of the hygro-thermo-mechanical behavior of the masonry, flowingly are presented the dimensional/physical properties and mechanical/ hygrothermal characteristics of the masonry units of massive autoclaved aerated concrete and lightweight concrete blocks with expanded clay aggregate, and of massive ceramic bricks.

6.1 Dimensional and Physical Properties of the Masonry Units

The geometry of the autoclaved aerated concrete blocks, lightweight concrete blocks with expanded clay aggregate and bricks, and individual dimensions (length, height, thickness) are represented in Figure 7, [31].

The net dry density and moisture content of the individual specimens and mean net dry density of the sample of the autoclaved aerated concrete blocks, lightweight concrete blocks with expanded clay aggregate 772-13:2000, Methods of test for masonry units — Part 13: Determination of net and gross dry density of masonry units (except for natural stone) and their results are presented in Appendix in Table 5: autoclaved aerated concrete blocks - X1 to X6; lightweight concrete blocks with expanded clay aggregate - Y1 to Y6; and bricks - X1 to X6), [31].

Length (l_u)=600 mm
Width (w_u)=150 mm
Height (h_u)= 200 mm

a) Autoclaved aerated concrete blocks

Length (l_u)= 490 mm
Width (w_u)=145 mm
Height (h_u)= 190 mm

b)Lightweight concrete blocks with expanded clay aggregate

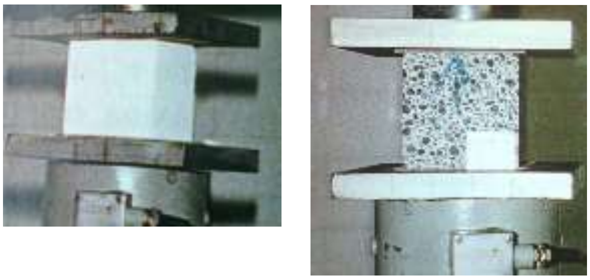
Length (l_u)= 228 mm
Width (w_u)=120 mm
Height (h_u)=73mm

c)bricks

Fig. 6: Schematic view of autoclaved aerated concrete blocks, lightweight concrete blocks with expanded clay aggregate and bricks, [31]

6.2 Mechanical Characteristics

The compressive strength of the individual specimens and mean compressive strength of the sample of each type of block/bricks (mean value of the strength of the individual specimens) of the ceramic blocks are determined based on the norm EN 772-1:2011+A1:2015 - Methods of test for masonry units - Part 1: Determination of compressive strength, [13], and their results are presented in Table 6: autoclaved aerated concrete blocks - Cx1 to Cx5; lightweight concrete blocks with expanded clay aggregate - Cy1 to Cy4; and bricks - Cz1 to Cz3; Figure 8), [31].



a) autoclaved aerated concrete b) lightweight concrete blocks with expanded clay aggregate

Fig. 7: Aspect of the compressive strength test of individual specimens extruded from masonry block/brick, [31]

a) Lightweight concrete blocks with expanded clay aggregate b) Bricks

Fig. 8: Aspect of the tensile strength test of the individual specimens, [31]

Table 6. Compressive strength of the individual specimens and mean compressive strength of the sample (mean value of the strength of the individual specimens) of the three types of blocks, [31]

Nº of the block	Section area (cm^2)	Maximum load F (kN)	Compressive strength (N/mm^2)	Mean compressive strength (N/mm^2)
Cx1	100	38.275	3.828	3.9
Cx2	100	39.036	3.904	
Cx3	100	39.036	3.904	
Cx4	100	37.262	3.726	
Cx5	100	40.810	4.081	
Cy1	100	105.955	10.596	10.1
Cy2	100	99.871	9.987	
Cy3	100	94.802	9.480	
Cy4	100	102.152	10.215	
Cz1	43	119.389	28.260	27.1
Cz2	43	123.445	29.220	
Cz3	43	100.632	23.818	

Section area: 40 mm x 40 mm (h_u x w_u)
Compressive strength: F/(h_u x w_u)

Table 7. Flexure tensile strength of the individual specimens and mean tensile strength of the sample (mean value of the strength of the individual specimens), [31]

Nº of the block	Section area (cm^2)	Maximum load F (kN)	Tensile strength (N/mm^2)	Mean Tensile strength (N/mm^2)
Tx1	16	0.489	1.376	1.3
Tx2	16	0.538	1.513	
Tx3	16	0.391	1.101	
Tx4	16	0.440	1.239	
Tx5	16	0.391	1.101	
Tx6	16	0.489	1.376	
Tx7	16	0.489	1.376	
Ty1	16	1.028	2.890	2.7
Ty2	16	0.881	2.447	
Ty3	16	0.881	2.447	
Ty4	16	1.076	3.028	
Ty5	16	0.832	2.339	
Ty6	16	0.979	2.752	
Ty7	16	0.930	2.615	
Tz1	16	2.251	6.330	5.5
Tz2	16	1.761	4.954	
Tz3	16	2.006	5.642	
Tz4	16	1.859	5.229	

Gross área: (l_u x w_u) were
Compressive strength: F/(l_u x w_u)

The flexure tensile strength of the individual specimens (flexure tensile strength, f_x ((N/mm^2) calculated by the equation of $f_x = (3.F. L)/(2.\ h_u \times w_u{}^2)$; L is the distance between supports; Figure 9), and mean tensile strength of the sample of each type of blocks/bricks (mean value of the strength of the individual specimens) of the ceramic blocks are determined, and their results are presented in Table 7: autoclaved aerated concrete blocks - Tx1 to Tx7; lightweight concrete blocks with expanded clay aggregate - Ty1 to Ty7; and bricks - Tz1 to Tz4).

6.3 Hygrothermal Characteristics of the Masonry Units

Masonry units (particularly, clay bricks and concrete units) usually expand when wet and shrink when dry, and, therefore, the dimensional and weight variations of masonry units subjected to moisture and temperature changes can occur in case of environmental actions on the building envelope, [1], [32]. The heat capacity of a porous material, such as the case of masonry units, is associated with its moisture content. The moisture influence on the thermal conductivity of a wet porous material is often given as a linear relationship based on experimental values determined for different moisture content conditions.

Aiming the analysis of hygro-thermo-mechanical behavior of the masonry based on the autoclaved aerated concrete blocks and lightweight concrete blocks with expanded clay aggregate and the bricks, which were above assessed (in sections 7.1 and 7.2).in terms of relevant mechanical and hygrothermal properties of mass and dimensional variation, in the following, tests related to the determination of mass and dimensional variation of the constituent material of massive autoclaved aerated concrete and lightweight concrete blocks with expanded clay aggregate, and of massive ceramic bricks, when subjected to a cyclic variation of moisture and temperature, were previously made, [32], and relevant results are presented in the following.

Six cubic specimens (six cubic specimens with approximate dimensions (X1-X6 series):100 mm x 100 mm x 100 mm) of autoclaved aerated concrete (dry density - 560kg/m^3), lightweight concrete blocks with expanded clay aggregate (six cubic specimens with approximate dimensions (Y1-Y6 series):100 mm100 mm x 100 mm), and bricks (six prismatic specimens with approximate dimensions (Z1-Z6 series): 100mm x 100mm x 65mm) were subjected to a period of drying (3 days in a oven at a constant temperature of 70ºC and a relative humidity of about 20%) followed by a period of 3 days stored in laboratory conditions (closed ambient room - 20ºC ± 5º and relative humidity 45% ± 5%) and followed again by a period of immersion in water (7 days), [32]. The specimens were then stored in laboratory conditions for 1 day (the 14th day). The specimens were then subjected to a second cycle with a similar methodology to the first.

The results showed that, generally, the Y series (mean values) shrink during "dry" periods (0-2rd days and 14th-16th days) while the X and Z series expand during the same periods (Figure 10), even though in the second cycle the Z series did not reach positive values as the X series did. In the first immersion period (6th-13th days), the dimensional variation of the Z series exhibited a similar pattern to that of the X series; but a different type of progression was detected in the second dry period (20th-27th days) with a trend to a strong contraction of the specimens.

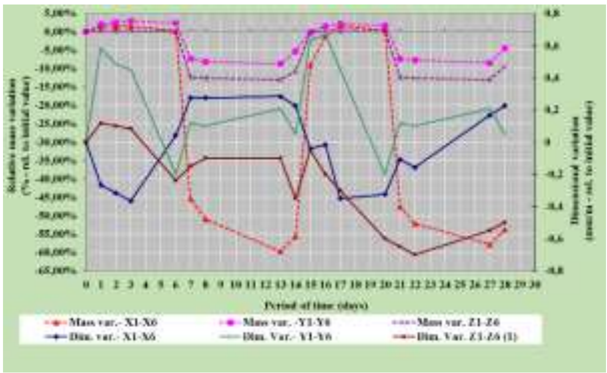


Fig. 9: Determination of mass and dimensional variation of the constituent material of massive autoclaved aerated concrete and lightweight concrete blocks with expanded clay aggregate, and of massive ceramic bricks, when subjected to a cyclic variation of moisture and temperature, [32]

6.4 Global Analyses of the Results

The results presented in section 6.1 of the net dry density and moisture content of the individual specimens and mean net dry density of the sample of the three types of blocks/bricks are correspondent to the current values usual for massive autoclaved aerated concrete and lightweight concrete blocks with expanded clay aggregate, and of massive ceramic bricks.

The results of compressive and tensile strength of the individual specimens of the three types of masonry units (constituent material of massive autoclaved aerated concrete and lightweight concrete blocks with expanded clay aggregate, and of massive ceramic bricks) and mean compressive strength of the sample (described in 6.2) showed distinct values between them.

The results of the temperature and moisture variation tests on series X1-X6 (autoclaved aerated concrete), Y1-Y6 (lightweight concrete with expanded clay aggregates), and Z1-Z3 (bricks) showed a dissimilar behavior in 1st cycle, the type of mass variation of these three series (X, Y, and Z) showed similar behavior in the 2nd cycle when compared with that in the 1st cycle, indicating an approximation to reversible behavior from the point of view of mass variation during these two cycles.

The results of these temperature and moisture variation tests on series X1-X6 (autoclaved aerated concrete), Y1-Y6 (lightweight concrete with expanded clay aggregates), and Z1-Z3 (ceramic bricks), revealed distinct characteristics of behavior between them, especially considering that the Y1-Y6 series (mean values) during "dry" periods loss their mass more than the other series (0-2nd days; 14th-16th days), [32]. During the "immersion" periods (6th -

13th days; 20th-27th days), the X1-X6 series (mean values) increased their mass clearly more than the other series, especially when compared with the Y series, while the Z series was very alike the Y series, [32].

From the type of dimensional variation shown by these three series, a slight tendency to similar behavior of the X and Y series in the 2nd cycle when compared with those obtained in the 1st cycle can be found. However, for the Z series, a different type of trend during the two cycles was evident, [32].

The effects of moisture on the mechanical behavior of URM infill walls and on their damage could be significant, (particularly, stress variation, creep, volumetric changes, and cracking). Contrariwise, the mechanical effects on moisture transfer, in the reverse coupling, can be significant in terms, particularly, of change of moisture transport.

The exposure to environmental actions, particularly related to the increase of moisture variations in building walls, has a degrading effect on the mechanical response of the material. As regards the influence of moisture on the mechanical response, the elastic properties and strength of the masonry may decrease due to the presence of moisture, [33], [34]. That adverse impact on the mechanical response can be caused, especially, by the upsurge of internal stresses and dimensional changes in these walls, that lead to a possible reduction of mechanical resistance associated with cracking (damage).

These effects of moisture variations and the mechanical response of masonry (this response could, particularly, depend on the behavior of blocks/bricks and mortar joints), could be taken into account: the degradation of the elastic properties can be included by introducing a dependence of the normal and tangential elastic stiffness coefficients, [33]. A typical Mohr failure criterion (yield surface) of the material of a masonry unit is presented in Figure 11.

It could be referred, about the failure criterion (yield surface) of masonry walls, that the reference values of the ratio shear stress/vertical compression stress could be determined based on EC6 (EN 1996-1-1: 2005), [35], where the peak shear strength of masonry could be calculated, approximately, based on the expression in EC6 for shear strength of masonry (EC6: 3.6.2 Characteristic shear strength of masonry), as follows in equation (1), where f_{vko} is the initial shear strength under zero compressive stress (cohesion); and σ_d is compressive stress perpendicular to the shear in the element

$$f_{vk} = f_{vk0} + 0.4.\sigma_d \qquad (1)$$

For example, for the initial shear strength of masonry, f_{vko}, from EC6, [EN 1996-1-1] (Table 3 and Table 4 - Values of the initial shear strength of masonry, f_{vko}), referred to the masonry unit of "Autoclaved Aerated Concrete (General purpose mortar of the Strength Class M2,5 - M9) and "Aggregate concrete" (General purpose mortar of the Strength Class M10-M20), it could be adopted the values of respectively 0.15 and 0.20.

Aiming to take into account the decreasing strength of the masonry, the Mohr-Coulomb failure criterion can be assumed dependent on the water saturation degree, [33]. Both the cohesion and the friction angle can vary, which leads to a change in the failure criterion, as illustrated in Figure 12 and Figure 13, with the modified failure zones due to the change in the maximum tensile stress and due to the modification of the friction angle, [33], [34].

Mechanical degradation is characterized by diffuse micro-cracking, which consents the description of the mechanical behavior through the classical damage mechanics, a commonly used approach based on taking into account the effects of the mechanical damage on the moisture diffusion process, [33], [34], [36], [37], [38], [39], [40].

In these three types of masonry units (blocks bricks) it is of interest the values of initial shear strength, f_{vko}, (estimation under zero compressive stress) of the bricks, and initial interface cohesion of mortar joint (estimation under zero compressive stress), friction angle ϕ (friction coefficient, $\mu=\tan\phi$) and Poisson's ratio, ν. of the bricks.

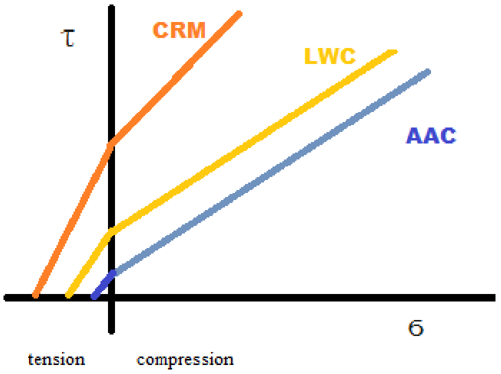


Fig. 11: Approximate representation of Mohr failure criterion of the three types of blocks/brick (Yield surface) - autoclaved aerated concrete blocks -AAC; lightweight concrete blocks with expanded clay aggregate - LWC; and bricks - CRM

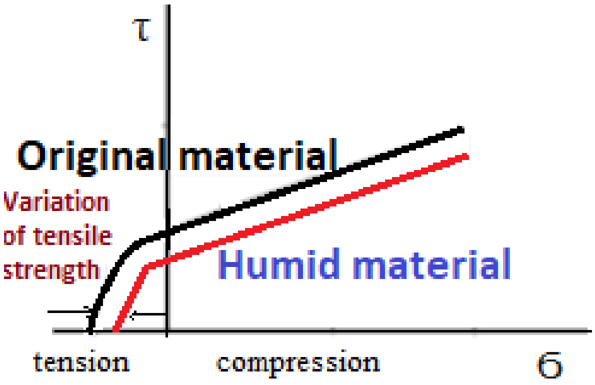


Fig. 10: Influence of degree of moisture on the Mohr failure criterion with variation of tensile strength

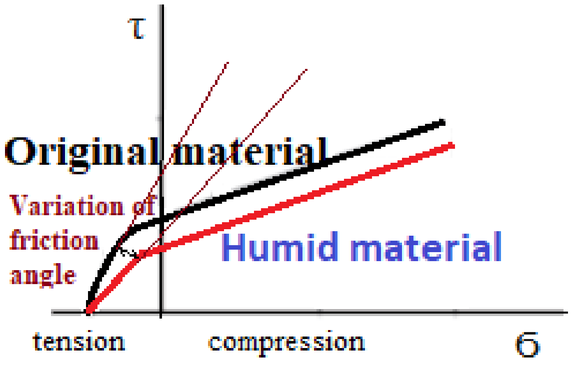


Fig. 11: Influence of degree of moisture on the Mohr failure criterion with variation of friction angle

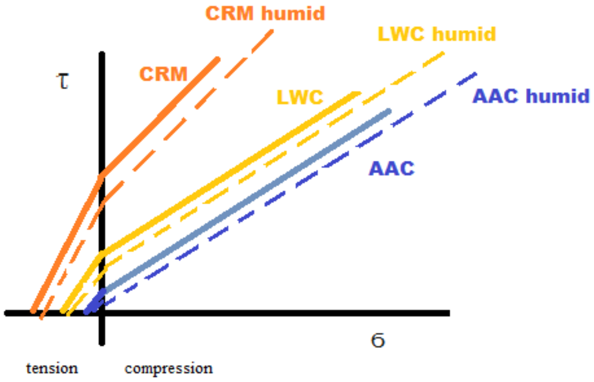


Fig. 12: Approximate representation of the influence of the degree of moisture on the Mohr failure criterion with a variation of friction angle-autoclaved aerated concrete blocks -AAC; lightweight concrete blocks with expanded clay aggregate - LWC; and bricks - CRM

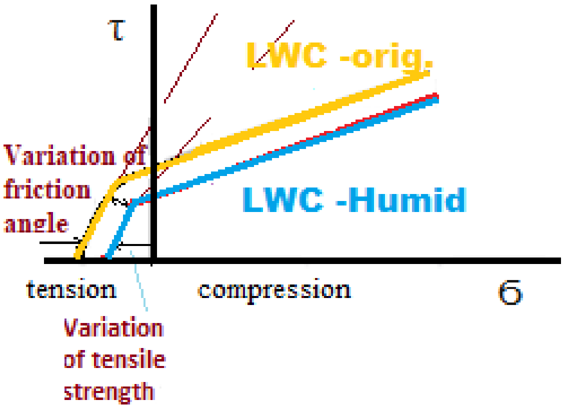


Fig. 13: Approximate representation of the influence of the degree of moisture on the Mohr failure criterion with a variation of tensile strength and friction angle, for a particular example of lightweight concrete blocks with expanded clay aggregate (LWC)

Based on the triaxial tests referred to before, [31], the estimated values for the following parameters are presented in the following: initial shear strength – AAC blocks – 0.92 MPa; LWC blocks – 2.26 MPa; CRM bricks – 4.09 MPa; friction angle ϕ (friction coefficient, μ) – AAC blocks - 39º (degrees); LWC blocks - 42º (degrees); CRM bricks - 54º (degrees).

An approximate representation of the influence of the degree of moisture on the Mohr failure criterion with variation of friction angle (autoclaved aerated concrete blocks - AAC; lightweight concrete blocks with expanded clay aggregate - LWC; and bricks – CRM) is presented in Figure 14.

Also, an approximate representation of the influence of the degree of moisture on the Mohr failure criterion with a variation of tensile strength and friction angle, for a particular example of lightweight concrete blocks with expanded clay aggregate (LWC) is presented in Figure 15.

To consider the effects of the mechanical damage on the permeability, it could be considered that the mechanical damage increases the effective porosity, and, influences the intrinsic permeability of the porous medium, [33].

Environmental-based solutions of masonry walls, especially regarding solutions of URM infill walls based on masonry units made with bio-based and waste materials are supposed, in certain cases, to be significantly porous and the influence of degree of moisture on the Mohr failure criterion with variation of tensile strength and of the friction angle could be meaningfully high.

Precipitation accompanied by intense wind is the principal agent accountable for the wetting of building envelopes. Degradation of the building vertical envelope due to cracking of the URM infill wall (associated for example with temperature and moisture cyclic variations) could modify the permeability of these external surfaces to the rain with a horizontal velocity component given by the wind (wind-driven rain (WDR)).

The previewed more intense rain and increase in temperatures due to climate changes will accentuate the adversity of present environmental conditions in terms of water penetration through the cracking in the walls. Taking into account the scenarios corresponding to assessments of projected future changes using Representative Concentration Pathways (RCPs) hygrothermal effects should be considered to influence the durability of the buildings, [1]. An added intensification of hygrothermal effects could be forecast for scenario of high greenhouse gas emission, about RCP 8.5, when compared to the monitoring that can be advised for the scenario of low greenhouse gas emission, Scenario A, about RCP 4.5, being the first scenario (RCP 8.5), less favorable, supposed to lead to predictable greater intensity of rain and higher increase in temperature variations due to climate changes, relatively to that previewed for RCP 4.5 scenario, [1].

7 Conclusions

An evaluation was here made of basic performance characteristics of current and environmental-based solutions of masonry walls of buildings. For that purpose, basic elements about masonry wall characteristics were described, particularly referring to the main types of masonry units and mortar joints, with a description of the current and environmental-based solutions mainly based on masonry units made with bio-based and waste materials. Subsequently, a general description of the relevant performance requirements of these types of URM infill walls was presented. Finally, the assessment of relevant mechanical and hygrothermal properties of particular types of masonry units was made.

Regarding the contributions of this work concerning previous works in literature, a comprehensive analysis of the basic performance characteristics of current and environmental-based solutions of masonry walls of buildings is considered to have been suitably made in this paper, with positive repercussions in terms of their better knowledge. Particularly it was highlighted in this paper the degrading effects on the mechanical response of the material exposure to environmental actions especially related to the increase of moisture variations in building walls, namely certain effects of moisture on the mechanical behavior of URM infill walls and on their damage, which were considered that they could be significant.

That knowledge could be useful, in terms of the practical applicability for the analysis of the performance behavior of current and environmental-based solutions of infill masonry walls of reinforced concrete buildings, particularly the assessment of mechanical and hygrothermal characteristics.

Thus, it is admitted that the present paper can provide, for future scientific research and technical work, a helpful reference for the assessment of mechanical and hygrothermal characteristics of URM infill walls and, eventually, in the corresponding classification of masonry materials/products studies.

As possible future developments of this work, it is recommendable that should be further studied, deeply, the specific differences between current and environmental-based solutions of infill masonry walls of reinforced concrete buildings, particularly regarding the influence of moisture content on the mechanical response (elastic properties and strength) of these types of masonry.

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APPENDIX

Table 5. Net dry density and moisture content of the individual specimens and mean net dry density of the sample of the three types of blocks

Block	Mass of the specimen after drying $m_{dry,s}$ (g)							
	Dimensions l/h/w	Effective volume (dm3)	Mass of the specimen			Moisture content (%)	net dry density	
			mass before drying m_0 (g)	mass after removing from the oven drying $m_{dry,s}$ (g)	mass after drying for 6 hours Md (g)		Net dry density	Mean net dry density
X1	1004 1004 1004	1013	671	562	565	19.4	555	560
X2	1004 1006 1007	1017	702	562	562	25.4	551	
X3	1010 1006 996	1015	702	574	574	22.7	564	
X4	1007 1008 1006	1020	672	576	576	17.3	562	
X5	1005 1009 1006	1016	704	572	572	23.7	560	
X6	1005 1010 1005	1020	696	580	580	20.6	566	
Y1	1007 1007 1013	1026	1104	1038	1039	6.4	1012	1040
Y2	1008 999 1008	1027	1147	1077	1079	6.5	1049	
Y3	1005 1009 1001	1020	1179	1093	1093	7.9	1072	
Y4	1010 1010 1002	1029	1164	1089	1090	6.9	1058	
Y5	1013 1014 1011	1031	1173	1093	1094	7.3	1060	
Y6	1011 1006 1008	1030	1179	1017	1018	6.1	987	
Y7	1004 1006 1014	1028	1151	1081	1082	6.5	1051	
Y8	1007 1010 1003	1024	1185	1013	1114	6.5	1087	
Y8	1003 1010 1012	1026	1181	1106	1107	6.8	1077	

$m_{dry,s}$ is the mass of the specimen after drying, (g)

Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

José Dias had the ideas and was responsible for formulation of overarching research goals and aims of this paper; he was responsible for conducting the research and for the development of the methodology of the study; he has organized the experiments referred in the sub-section 5.2 and section 6, and was responsible for their execution; he as carried out the preparation, creation of the published work.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

The Planned Research Programme of the “National Laboratory of Civil Engineering” (LNEC) has funded the present study.

Conflict of Interest

The author has no conflict of interest to declare.

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