Characterizing unreinforced masonry through core testing

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Abstract. Estimating the mechanical properties of existing masonry structures still represents a challenge since there is the need to find a balance between the invasiveness of the testing method and the accuracy and representativeness of the test results. Minor destructive tests are usually preferred, especially when dealing with historical constructions. In the last decades, the use of masonry cores, tested to obtain either compression or shear properties, has progressively become a valid and promising alternative to other testing methods. However, the application of core testing is often limited to the academic research, mainly due to the lack of specific standards and testing guidelines. The objective of the present work is to analyze procedures adopted to test masonry cores for the characterization of compressive properties of unreinforced masonry with regular units. Through the collection of a database, an inventory of available experimental data on various masonry is provided, and the main features of test setups and protocols are examined and compared. Factors influencing the results, such as boundary conditions, geometry of the samples, bond pattern, etc., are identified. Collection of data related to standard experimental tests is also performed to support the definition of specific correlations between the results of core testing and of standard procedures, and, in general, to evaluate the reliability of the different testing methodologies. The present research represents the basis for a possible standardization of core testing methods.

Keywords: Masonry, Minor Destructive Tests, Core Testing, Compression.

1 Research overview

With the objective of providing a contribution for the harmonization of masonry core testing procedures, specifically focusing on compressive properties evaluation, in the present research a collection of data is performed considering different data sources, i.e., journal and conference papers, technical reports, etc. The activity is carried out in the framework of the RILEM Technical Committee on “Testing methods for masonry cores” (CTM) [1], which has started in 2024 and involves academic researchers around the world.

To determine compressive properties of unreinforced masonry with regular units by testing cores, after the extraction procedure, the core samples must be capped with a high-strength material, typically steel or cementitious mortar. The role of the cap is providing confinement to the core sample, thus reproducing the in-situ condition of masonry before the extraction, and ensuring planar surfaces for the compressive load application. Compressive tests on cores were performed in the past with various setups and testing protocols, considering both single- and double-wythe cores with different diameters and bond patterns, and adopting different geometries for the high-strength cap [2-4]. Due to these variations, by comparing the masonry compressive strength obtained from tests on cores and the results determined through standard tests, e.g., uniaxial compression tests on masonry wallettes or prisms, different correlations were found [5]. To propose testing guidelines, there is the need to understand the role of each factor in influencing the core test outcomes. For this reason, a specific data collection was planned among the participants of the RILEM Committee CTM.

To setup the database, the following information was collected from literature [3,4,6-17]:

- Masonry typology, with indications about the size and type of units, the mortar type and average joint thickness, and the construction year differentiating between lab-replicated and field-extracted masonry specimens.
- Mechanical properties of units and mortar, in terms of compressive strength, flexural strength and elastic modulus.
- Cap material, geometry, and mechanical properties in terms of compressive, flexural, tensile strength and elastic modulus.
- Core geometry in terms of length, width, thickness, number of wythes, and core bond pattern (refer to Fig.1 for the classification of the different bond patterns identified in the database).
- Results of tests on core, in terms of compressive strength and, when available, stress at first cracking, elastic modulus, and crack pattern. The stress calculation method, i.e., either considering the diametral surface of the core (area of core) or the cap surface (area of cap), is also noted.
- Results of companion tests on wallettes or prisms, in terms of compressive strength and elastic modulus, obtained through standard test methods, e.g., uniaxial compressive tests on wallettes according to EN 1052-1.

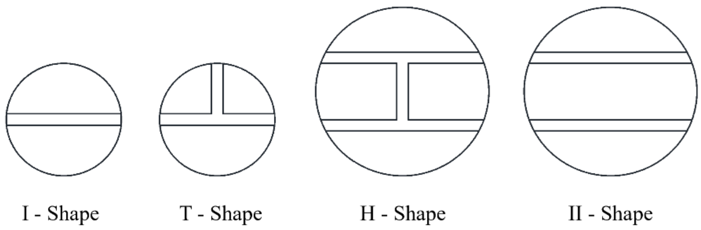

Fig. 1. Classification of core bond patterns.

Data were gathered both from tests on lab-replicated and field-extracted samples from existing buildings or bridges. They were classified in datasets based on the masonry typology, environmental exposure conditions (e.g., sample extracted from walls with north/south exposure in an existing building), and cap/core characteristics. Up to date, the database for compression properties includes 39 different masonry typology and 97 different datasets. Among those, 71 datasets include both experimental results obtained by tests on core and tests on wallettes/prisms as suggested by current standards.

In the following, preliminary results are presented showing the composition of the database and focusing on the main properties which can influence the core test results. In terms of masonry typologies, calcium silicate and clay brick masonry typologies were identified. The clay brick masonry typology is the prevalent one (92%), characterized by a wide range of normalized brick compressive strength, i.e., 10-45 MPa (Fig. 2*a*). Different mortar compositions were found, i.e., cement-, lime-, lime-cement, and lime-truss based, with a prevalence of lime-based mortar mixes (46%), and compressive strength lower than 15 MPa in most cases (Fig. 2*b*). The experimental test series were performed both on lab-replicated masonry specimens (48%) and on field-extracted ones (52%).

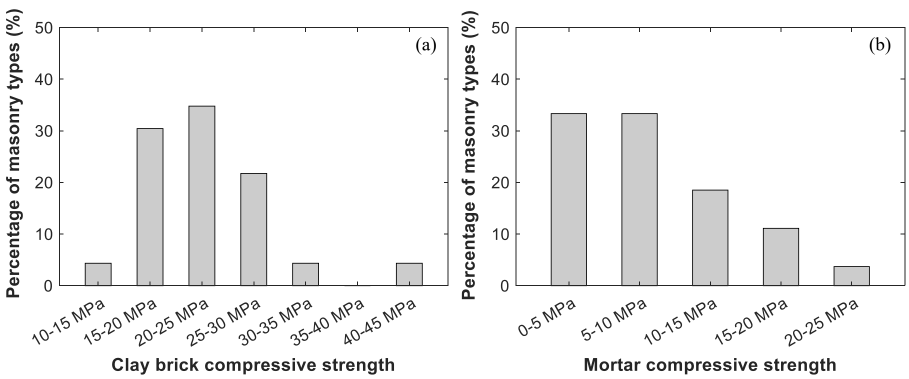

Fig. 2. Percentage of masonry typologies per (a) normalized brick compressive strength classes, (b) mortar compressive strength classes.

Several variations in core's geometry and bond pattern are present in the database. The majority of the cores were single-wythe specimens (79%), and two different diameter values were considered in the cited research, i.e., 100 mm (58%) and 150 mm (42%). The bond patterns identified in the database are presented in Fig. 3*a*, where the "irregular" bond pattern was also included, for those cases in which the layout of bed and head joints could not be related to the previously identified bond patterns (Fig. 1). Regarding the cap, high-strength mortar was adopted in the 82% of the cases, while only for the 18% of the datasets the steel cradles were used. To analyze the confinement given by the cap to the core, an important parameter to be assessed is the ratio between the length of the cap and the core diameter, ranging between 0.5 and 1, as can be seen in Fig. 3*b*. To evaluate the reliability of the results, the number of samples tested for each dataset was also collected, and it is worth mentioning that the majority of the datasets included at least 3 test repetitions.

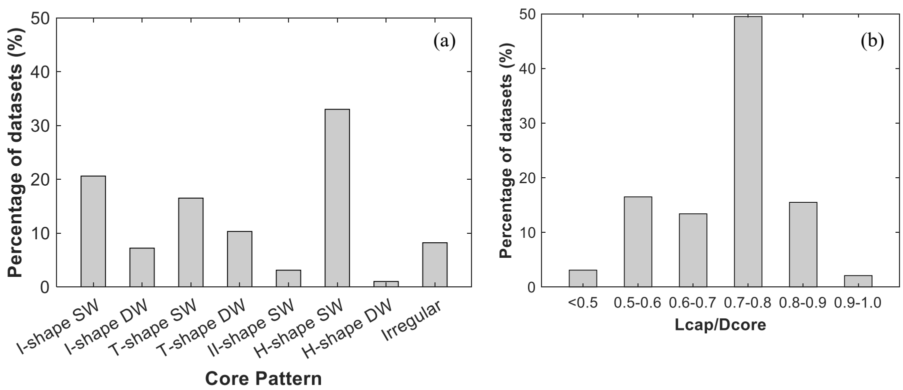

Fig. 3. Percentage of datasets per (a) bond pattern (SW: single-wythe, DW: double-wythe, refer to Fig. 1 for the classification) and per (b) cap length-to-diameter ratio.

In conclusion, the data collection was useful to obtain an overview of the testing procedures adopted in past research for the determination of compressive properties of masonry from cores. A variety of factors can influence the test outcomes and a preliminary analysis of the collected data allowed to identify the prevalent masonry typologies and sample geometries, needed for a further and more refined classification of the data. The dataset available and their variety in features provide confidence that crucial factors influencing the outcome of compression tests on core can be identified. This will support the work of the RILEM technical committee CTM in drawing testing guidelines, fostering the use of core testing method in engineering research and practice.

References

1. Esposito R, Ferretti F (2024) Testing Methods for Masonry Cores: A way forward to increase reliability of mechanical properties evaluation. RILEM Technical Letters 9:93–97. DOI: https://doi.org/10.21809/rilemtechlett.2024.207
2. Ispir M, Demir C, Ilki A, Kumbasar N (2010) Material characterization of the historical unreinforced masonry Akaretler row houses in Istanbul. Journal of Materials in Civil Engineering 22(7):702-713. DOI: https://doi.org/10.1061/(ASCE)MT.1943-5533.0000071
3. Sassoni E, Mazzotti C (2013) The use of small diameter cores for assessing the compressive strength of clay brick masonries. Journal of Cultural Heritage 14(3):e95-e101. DOI: https://doi.org/10.1016/j.culher.2012.11.027

4. Pelà L, Canella E, Aprile A, Roca P (2016) Compression test of masonry core samples extracted from existing brickwork. Construction and Building Materials 119:230-240. DOI: https://doi.org/10.1016/j.conbuildmat.2016.05.057
5. Jafari S, Esposito R, Rots JG (2017) Literature review on the assessment of masonry properties by tests on core samples. In: 4th Int. WTA PhD Symposium Proceedings, pp. 173–180. WTA Nederland-Vlaanderen.
6. Sassoni E, Mazzotti C, Pagliai G (2014) Comparison between experimental methods for evaluating the compressive strength of existing masonry buildings. Construction and Building Materials 68:206-219. DOI: https://doi.org/10.1016/j.conbuildmat.2014.06.070
7. Pelà L, Roca P, Benedetti A (2016) Mechanical Characterization of Historical Masonry by Core Drilling and Testing of Cylindrical Samples. International Journal of Architectural Heritage 10(2–3):360–374. DOI: https://doi.org/10.1080/15583058.2015.1077906
8. Matysek P, Stryszewska T, Kańka S (2016) Experimental research of masonry compressive strength in the Auschwitz II - Birkenau former death camp buildings. Engineering Failure Analysis 68:263-274. DOI: https://doi.org/10.1016/j.engfailanal.2016.06.007
9. Matysek P (2016) Compressive strength of brick masonry in existing buildings—research on samples cut from the structures. In: Modena C, da Porto F, Valluzzi MR (eds) Proceedings of the 16th International Brick/Block Masonry Conference (IB^{2}MaC 2016). CRC Press, London. DOI: https://doi.org/10.1201/b21889
10. Jafari S, Rots JG, Esposito R (2019) Core testing method to assess nonlinear behavior of brick masonry under compression: A comparative experimental study. Construction and Building Materials 218:193-205. DOI: https://doi.org/10.1016/j.conbuildmat.2019.04.188
11. Pelà L, Saloustros S, Roca P (2019) Cylindrical samples of brick masonry with aerial lime mortar under compression: Experimental and numerical study. Construction and Building Materials 227:116782. DOI: https://doi.org/10.1016/j.conbuildmat.2019.116782
12. Segura J, Pelà L, Roca P, Cabané A (2019) Experimental analysis of the size effect on the compressive behaviour of cylindrical samples core-drilled from existing brick masonry. Construction and Building Materials 228:116759. DOI: https://doi.org/10.1016/j.conbuildmat.2019.116759
13. Matysek P, Seręga S. (2020) Assessment of brick masonry strength using tests on core samples cut from the structures. In: Kubica B, Kwiecień A, Bednarz L (eds) Proceedings of the 17th International Brick/Block Masonry Conference (IB^{2}MaC 2020), Kraków, Poland. DOI: https://doi.org/10.1201/9781003098508-83
14. Ferretti F, Incerti A, Mazzotti C (2020) Comparison Between Investigation Techniques for the Evaluation of the Compressive Properties of Brick Masonry Structures. In: Roca P, Pelà L, Molins C (eds) 12th International Conference on Structural Analysis of Historical Constructions (SAHC 2020), Barcelona, Spain, DOI: 10.23967/sahc.2021.051
15. Dorji J, Zahra T, Thambiratnam D, Lee D (2021) Strength assessment of old masonry arch bridges through moderate destructive testing methods. Construction and Building Materials 278:122391. DOI: https://doi.org/10.1016/j.conbuildmat.2021.122391
16. Li X, Esposito R (2023) A strategy for material characterisation of multi-wythe masonry Infrastructure: Preliminary study. Construction and Building Materials 408:133600. DOI: https://doi.org/10.1016/j.conbuildmat.2023.133600
17. Ferretti F, Incerti A, Mazzotti C (2025) Determination of Masonry Compressive Strength Properties by Testing Cores. In: Milani G, Ghiassi B (eds) 18th International Brick and Block Masonry Conference (IB^{2}MaC 2024). Lecture Notes in Civil Engineering 614, Springer, Cham. DOI: https://doi.org/10.1007/978-3-031-73310-9_84