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Analysis of the compressive strength of commercial concrete blocks for structural masonry in Ciudad del Carmen, Campeche

Análisis de la resistencia a compresión de blocks de concreto comerciales para mampostería estructural en Ciudad del Carmen, Campeche

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Abstract

In the municipality of Carmen, Campeche, masonry constructions are a common practice due to the availability of materials and labor. However, the lack of quality control in the mechanical properties of these materials poses a significant challenge, given the absence of regulation regarding the components of blocks and mortar. The majority of block pieces are imported from various states in the Mexican Republic, leading to significant variations in their characteristics. In response to this issue, a research initiative was conducted to assess the strength of the concrete blocks marketed in the region. While most meet the minimum specifications, values below the recommended standards were identified, emphasizing the urgent need to establish more rigorous quality control mechanisms. This measure contributes to ensuring structural safety in the construction of traditional homes, highlighting the importance of implementing stronger practices that contribute to the integrity of buildings in the locality. During the process of acquiring block pieces, some were not classified for a specific structural function, representing a significant alert for structural safety purposes.

Block, Masonry, Concrete, Regulation, Structural

Resumen

En el municipio de Carmen, Campeche, las construcciones de mampostería son de uso cotidiano debido a la disponibilidad de materiales y mano de obra. No obstante, la falta de control de calidad en las propiedades mecánicas de estos materiales presenta un desafío significativo. Frente a esta problemática, se llevó a cabo una investigación para evaluar la resistencia de los bloques de concreto comercializados en la región. Aunque la mayoría cumple con las características mínimas, se identificaron valores por debajo de las recomendaciones, subrayando la necesidad imperante de establecer mecanismos de control de calidad más rigurosos. Esta medida se torna esencial para garantizar la seguridad estructural en la construcción de viviendas tradicionales, destacando la importancia de implementar prácticas más sólidas que contribuyan a la integridad de las edificaciones en la localidad. Durante el proceso de adquisición de piezas de blocks, algunas de estas no estaban clasificadas para una función estructural determinada, lo que representa una alerta importante para fines de seguridad estructural.

Bloque, Mampostería, Concreto, Normatividad, Estructural

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Introduction

Concrete block is mainly used as a building material for partition walls with and without structural function. These form part of the elements of structural masonry. However, the mechanical properties of masonry are more variable and difficult to predict than those of other structural materials such as reinforced concrete or structural steel. This is because there is little control over the properties of the component materials, local materials are generally used, and fabrication procedures are not standardised.

One of the variables that must be evaluated in both industrial and artisanal production is the geometric aspect of the block pieces, which can be regulated by proposing moulds that meet the requirements according to current regulations, as proposed by Lastra et al. (2021). Recent research on environmentally sustainable block elements, as reported by Elbashiry et al. (2023), indicates that compressive strength is an important factor for the overall performance of the element. Medeiros et al. (2023) conducted experimental tests to evaluate the residual stresses in hollow blocks made through vibro-compressed and dry consistency processes after exposure to high temperatures, the results confirmed the low influence of the compressive stress on the evolution of the residual mechanical strength and the strong influence of the type of aggregate on the failure behaviour of the part.

Other researchers, such as Ahmad et al. (2023), carried out studies considering recycled aggregates, where special treatments are required to bond the elements that make up the block mix. The results obtained in the present research indicate significant variation in the aggregates that make up the concrete mix to produce the blocks, since they come from different states of the Mexican Republic, which contributes to the uncertainty of the mechanical characteristics, including compressive strength.

The structural behaviour of masonry has been the subject of a wide range of experimental and analytical studies, which have resulted in the development of standards for the quality control of the elements that constitute it. However, in the municipality of Carmen, Campeche, no regulations have been issued for the minimum mechanical parameters that guarantee structural safety.

Due to the large number of housing developments built with masonry, it is necessary to guarantee the quality of the materials, being the compressive strength one of the factors to be considered for its verification.

Traditionally, the standards used for structural design of masonry use as a reference the Complementary Technical Standards for the Design and Construction of Masonry Structures, of the Mexico City Building Regulations, the current one being the recently published NTC-masonry (2023). This document includes the minimum requirements for the analysis, design, detailing and construction of structures based on masonry walls. This standard only allows the design and construction of new structures of artificial parts based on confined or internally reinforced masonry, aspects that have been standardised to ensure the uniform construction of buildings, especially in Mexico City.

The standardisation process requires sampling, various experiments and standardised procedures such as the analysis presented by Tena et al. (2017) where they report results of the research carried out for the purposes of the proposal of the Complementary Technical Standards for the Design and Construction of Masonry Structures in its 2017 version. The researcher and collaborators report the variability of physical and mechanical properties of these masonry elements that include mortar, block pieces and partition walls.

The quality control parameters of masonry include aspects such as volumetric weight, absorption among others, being the compressive strength of the pieces the most important one on which the mechanical properties of masonry walls depend. Therefore, its determination is required for quality control purposes (NTC-masonry, 2023).

Methodology

Currently, research is being carried out to develop a proposal for masonry standards in the Municipality of Carmen, Campeche. The activities include a sampling of material available in material shops in the region, as well as the results reported in the technical literature on the subject.

Mechanical testing of block parts

The mechanical testing of blocks must be carried out by means of standardised procedures indicated in the current NMX Standards. Once the quality is guaranteed, the structures must be built, whose analysis, design and construction procedures are included in the aforementioned NTC-masonry (2023). The review includes a review of geometric and mechanical aspects, which are presented below.

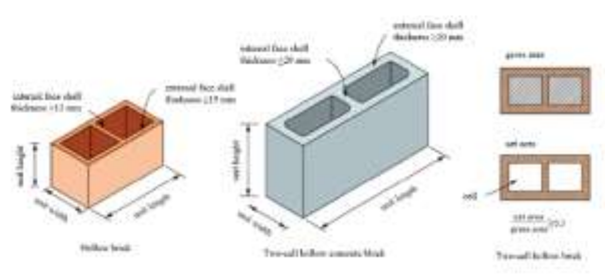
Classification of parts

Solid parts

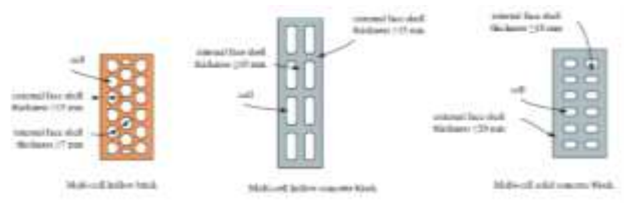
For the purposes of application of Chapter 5 of NTC-earthquake (2023) and NTC-masonry (2023), solid members are considered to be those that have a net area of at least 75 per cent of the gross area in their most unfavourable cross-section, and whose external walls have a thickness of not less than 20 mm.

Hollow parts

The hollow parts referred to in the Standards and Chapter 4 of NTC-earthquake (2023) are those which have, at their worst case cross-section, a net area of at least 50 per cent of the gross area; in addition, the thickness of their outer walls is not less than 15 mm (Figure 1a). For hollow parts with two to four cells, the minimum thickness of the inner walls shall be 13 mm. For multiperforated parts, whose perforations are of the same dimensions and evenly distributed, the minimum thickness of the inner walls shall be 7 mm. Multi-perforated parts are defined as those with more than seven perforations or pockets (Figure 1b). For the purpose of NTC-masonry (2023) only hollow sections with cells or perforations orthogonal to the supporting face are permitted.



(a) Hollow parts



(b) Multi-perforated parts

Figure 1 Geometric requirements for structural masonry parts according to NTC-masonry 2023. (a) Geometric requirements for hollow parts, (b) Requirements for multiperforated parts (NTC-masonry 2023)

Estimation of the compressive strength according to NMX-C-036-ONNCE standard

This standard establishes the test method for the determination of compressive strength. All blocks, bricks, partitions and brickwork made of any material are included in this standard. For any use, the case of partitions for infill or structural walls, and the case of pavers for non-road walkways, the special strength specifications with which they have to comply shall be consulted in the standards NMX-C-404 (2012) and NMX-C-036 (2013), respectively.

To carry out this test it is necessary to have the sulphur mortar which must have a minimum compressive strength of 34. 3 MPa (350 kgf/cm2), in addition to an electric oven that allows temperature regulation, a testing machine that must be equipped with two steel blocks, whose Rockwell C hardness is not less than 60 and Brinnell hardness N 620.

The surfaces of the blocks and load plates shall not differ from a plane by more than 0.025 mm in any one dimension in 152.4 mm. The centre of the sphere of the upper block must coincide with the centre of its load. If a load plate is used the centre of the spheres must fall on a line passing vertically on the centroid of the specimen load. The spherical seating block must be held fixed in place, but must rotate freely in any direction.

The diameter of the load face of the blocks must be at least 160 mm. Where steel plates are used between the load blocks and the specimen, they shall have a thickness equal to at least one third of the distance from the edge of the load block to the most distant corner of the specimen. In no case shall the plate thickness be less than 13 mm as shown in Figure 2.

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Figure 2 Steel plate

Pitch

A 445 mm x 250 mm plate, 18.5 mm thick, with two 6.5 mm thick plate borders 50 mm high was used to delimit two borders, to delimit the other two. Squares with 12 mm x 12 mm squares were used, one for each size of partition or block, to ensure that they were horizontal and that the sulphur mortar did not run out of the sides, as this would cause porosity or voids in the pitch and therefore the stresses would not be distributed uniformly.

Placement of the specimen

The specimen was positioned with the centroid of its surfaces to receive the load vertically with the centre of the steel load block of the testing machine. For homogeneous materials the centroid of the loading surface may be considered to be the vertical passing through the centre of gravity of the specimen.

Except for special units intended to be used with their bores in a horizontal direction, they are tested with their bores in a vertical position; for other units with bores intended to be used horizontally, they should be tested with their bores in the position in which they are to be used. This is important because it is a matter of testing the element under the conditions under which it will operate on site.

Test speed

The tests were carried out with a Universal Shimadzu UHx-1000 kN machine with a load application speed of 1.5mm/min, which was calibrated prior to carrying out the experiments in accordance with the suggestions of standard NMX-C-404 (2012).

To calculate the results it is necessary to take the compressive strength of a specimen as the maximum N (kgf) divided by the cross-sectional area of the specimen, i.e. the total area of a section perpendicular to the direction of the load including those in the hollow spaces, i.e. the solid area is considered.

$$R = \frac{F}{A} \tag{1}$$

Where:
R = Compressive Strength in MPa (kgf/cm^2)
F = Is the maximum load in N (kgf)
A = Is the cross sectional area of the specimen (cm^2)

The compressive strength is reported to the nearest 100 kPa (1.0 kgf/cm^2).

Definition of geometrical properties of the tested specimens

The dimensions indicated in Table 1 based on Figure 2 were determined according to the standard NMX-C-038 (2014) concerning the determination of the dimensions of parts forming part of masonry.

Ruler, square and vernier were used to determine the dimensions. The values shown in Table 1 correspond to real values and not averages by type or brand of piece, due to the fact that it was necessary to calculate the maximum stress for each piece. Also, the parts do not correspond to a sample of a batch, as required in most experiments for part strength determination purposes.

Figure 3 shows the diagrams for identifying the dimensions of the block parts studied, as well as the procedure for measuring the parts.

December, 2023 Vol.10 No.27 1-8

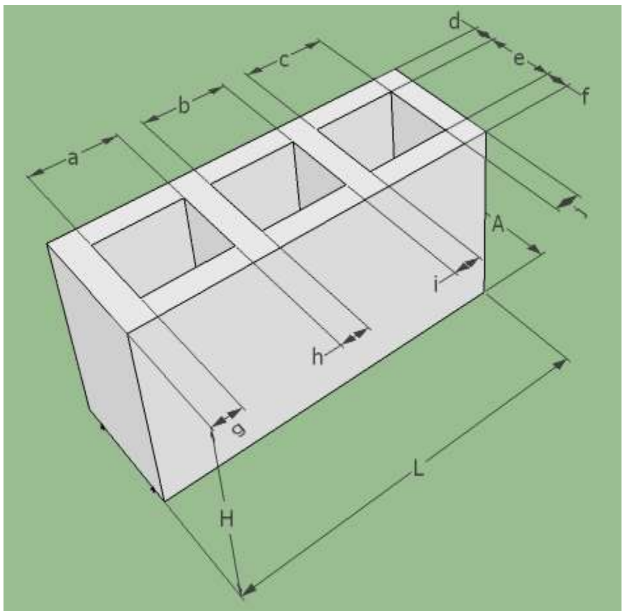


Figure 3 Diagram for identifying the dimensions of the pieces studied (Lastra I., 2017)

For the determination of the measurements shown in Table 1 and Table 2, the following concepts were considered.

Nominal measurement. This is the one that considers the real dimensions of the product, plus the thickness of the masonry joint.

Total area (gross). It is the result of multiplying the length by the width of the piece.

Net area (real). It is the effective surface of the piece, which is obtained by subtracting the area of the cells from the total area.

Solid piece. It is the one whose net area is equal or greater than 75% of its total area according to NMX-C-404 (2012).

Hollow piece. It is the one whose net area is less than 75 % of its total area, but greater than 40 % according to NMX-C-404 (2012).).

		Dimensions												
CASE	Weight (Kg)	a (cm)	b (cm)	c (cm)	d (cm)	e (cm)	f (cm)	g (cm)	h (cm)	i (cm)	j (cm)	L (cm)	A (cm)	H (cm)
01-010-3005A	12.2	9.1	9.1	9.3	3.1	8.6	3	3	3	3	3	39.5	14.8	19.8
01-011-3005A	12	10	10	10	2.5	9.6	2.5	2.5	2.5	2.5	2.5	39.3	14.6	19.6
02-001-3005A	11.8	9.1	9.2	9.1	2.9	8.8	2.9	2.9	3.2	3	2.7	39.5	14.4	19.5
02-002-3005A	12	9.8	9.8	9.8	2.5	9.4	2.5	2.5	2.5	2.5	2.5	39.5	14.5	19.5
03-001-3005A	9.3	9	9	9	2.9	3.8	2.9	2.9	3.5	3.5	2.9	39.5	9.5	19.3
03-002-3005A	9.2	9.5	9.5	9.5	2.5	4.3	2.5	2.5	2.5	2.5	2.5	39.5	9.5	19.5
04-001-3005A	5.7	11.5	4	11.5	2.7	8.7	2.7	2.5	2.5	2.5	2.5	39.2	14	19.0
04-002-3005A	6	11.5	4	11.5	2.8	8.4	2.7	2.5	2.5	2.5	2.5	39.2	14	19.0

Table 1 Geometric data of the block pieces studied

The block pieces studied are classified as hollow pieces, due to the fact that the net area in all cases is greater than 40% and less than 75% of the total area.

The nominal dimensions of the pieces should be based on the module of 10 cm in multiples or submultiples, including the 1 cm thick masonry joint. The minimum dimensions should be 10 cm high 10 cm wide and 30 cm long, according to Table 1 these minimum requirements are met. The wall dimensions should be at least 2.5 cm, in all cases the minimum dimension is fulfilled.

Analysis of the results from the stress-strain curve

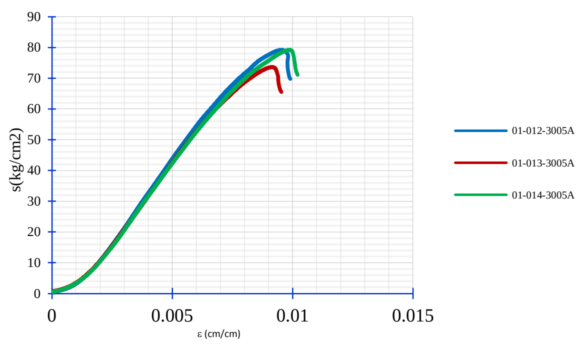
Brand 04 was tested, whose use and application consists of the construction of partition walls and upper floors. During the testing process, it was observed that the failure of the specimen started from the lower end and continued towards the point of application of the load. At the instant of reaching the maximum load the element did not disintegrate, however, the entire element showed cracking.

The stress-strain curves of specimens 01-012-3005A, 01-013-3005A and 01-014-3005A are shown in Graph 1. It is observed that the largest difference is presented in the load of the last piece of 45.03 Ton, 42.16 Ton and 45. 66 Ton respectively, which lead to stresses higher than the minimum allowed by the standard which is 60 kg/cm2, as indicated in Table 2. It is observed that up to a deformation of 0.005 the three cases coincide, which leads to a similar slope and sufficiently representative of the pieces. The most significant differences occur in the ultimate load, which is representative of the non-linear behaviour of the material and the inherent errors of the experiment and of course of the precision of the instrument used.

The results of specimens 02-001-3005A, 02-002-3005A and 02-003-3005A are shown in Graph 2. The greatest dispersion is observed in the stress-strain curve. When the surface was checked before the element was pitched, non-uniformity was observed.

In this case, the modulus of elasticity represented by the slope in the linear elastic range would have a small scatter, because the curves do not coincide. It is also observed that in the stage close to rupture all the cases differ and show different behaviours. Case 02-002-3005A showed the greatest difference as the load and deformation prior to rupture was reduced.

For mark 03, in the ascending branch with the exception of case 03-003-3005A they coincide. The minimum and maximum values were 22.51 Ton and 27.80 Ton, both cases with stresses greater than 60 kg/cm2. Unlike the previous cases, where the rupture occurred suddenly for all the cases of the 03 brand, the pieces show similar behaviour and a decrease in the load as the specimen reaches the maximum deformation and similar failure patterns.



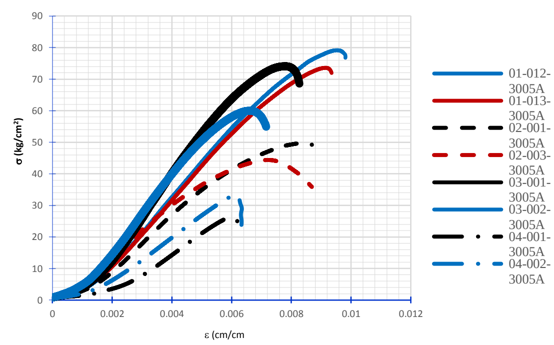
Graph 1 Stress-strain curve for brand 01 (Chuy and Flores, 2015).

This observed behaviour represents an advantage of the brand over the other cases studied. Another aspect observed was that the piece did not disintegrate in all cases, unlike brand 01, which, when reaching the ultimate load, bursting occurred in most of the cases tested.

Brand 04 showed the greatest dispersion. This piece had the lowest resistance with a minimum value of 14.25 Ton (04-001-30053A) and a maximum of 18.28 Ton (04-002-300A). The case 04-004-300A shows that reaching the maximum value, the downward curve decreased almost vertically unlike the case 04-001-3005A that showed higher deformation capacity. The other cases showed intermediate values.

Graph 2 compares parts of brands 01, 02, 03 and 04. This graph shows significant differences, however, this does not indicate that they do not comply with the corresponding standards, because their use can vary. However, it does reflect the importance of knowing the resistance a priori, because in the case of not knowing the use of the part, one could be on the side of insecurity and use lower resistances than necessary. Mark 03, which corresponds to the 10x20x40 specimen, shows intermediate values of stresses and desirable behaviour.

Although in professional practice only the maximum strength or maximum stress of the block is verified, in this research the stress-strain curves of the different brands studied are presented, which provides additional information.



Graph 2 Comparison between stress-strain curves for marks 1, 2, 4 of dimensions 15x20x40 cm and mark 3 of dimensions 10x20x40 cm

Table 2 shows the summary of the values of the pieces tested, the marks that comply with the minimum resistance are mark 01 and mark 03. In the case of brand 02, the use was not defined, however, the resistance in 4 cases is less than 60 kg/cm2. In the case of brand 04, the block was defined for use in partition walls or upper storey walls.

Caso	Área (cm^2)	σ_{max}(kg/cm^2)	σ_{min}(kg/cm^2)
01-010-3005A	584.6	64.99	60
01-011-3005A	576.7	68.68	60
02-001-3005A	568.8	49.71	60
02-002-3005A	572.75	48.86	60
02-003-3005A	572.75	44.39	60
03-001-3005A	375.25	74.1	60
03-002-3005A	375.25	59.99	60
04-001-3005A	548.8	25.97	NO DEFINIDO
04-002-3005A	548.8	33.31	NO DEFINIDO

Table 2 Summary of results of the block pieces tested in compression

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Conclusions

Structural masonry is widely used in medium-interest housing, for the same reason the quality control of the materials is limited. Due to the above, this research was carried out in order to obtain information to improve or regulate the mechanical characteristics and construction methods that will allow the proposal of a normative proposal that regulates the use of the materials that make up structural masonry.

The quality of the block pieces in general is not guaranteed by any official means, so the client lacks certainty of the minimum resistance.

The maximum resistance of the pieces of the studied brands of the same dimensions (15x20x40 cm) provided different resistances, two of them higher than the one indicated by the corresponding standard. The other brand purchased was classified by the supplier as being for "low levels" of load such as partition walls and upper floors. However, the obtained value of 35 kg/cm2 is lower than the recommended value for such cases.

The regulatory compliance requirements generally refer to geometrical aspects, and maximum strength, which can be verified in a quality control study. However, detailed analysis of the stress-strain curves shows additional important information such as the type of failure, which contributes to the ductility of the structural masonry system.

Recapitulating the conclusions

1. A revision and strengthening of the quality control mechanisms for masonry materials is required.

2. Procurement and control processes need to be improved to ensure that blocks meet the specifications necessary for their structural function.

3. The variability in the properties of masonry materials demands stricter regulation of both their geometric and mechanical characteristics.

4. The absence of local standards for minimum mechanical parameters puts the integrity of buildings at risk.

5. The NTC-masonry regulation (2023) is a step towards the establishment of minimum standards, but it needs to be adapted and complemented by local research.

6. Mechanical testing according to NMX standards is essential to verify quality and safety before the use of blocks in construction.

7. Detailed specifications for solid and hollow blocks are crucial to ensure their adequate structural performance.

8. Standardisation of compressive strength calculation and correct dimensions are fundamental to guarantee the quality of the material.

9. The variability found in strength between different brands underlines the need for informed and documented selection of materials to avoid structural failure.

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