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Comparative analysis of the physical and mechanical properties of clay bricks as a construction element from factories located in the northern area of the department of Valle del Cauca in Colombia

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Abstract

The production of construction materials must follow minimum quality parameters that guarantee their proper functioning in the works. For this reason, there is a need to establish control processes that demonstrate the durability and regulatory compliance of materials, in order to validate their properties and be used without any inconvenience. However, these manufacturing processes may vary, depending on the methods that each company applies and the materials that they implement, which can cause possible representative differences between the results of the tests of the materials when compared to each other. The purpose of this research is to carry out a comparative analysis of clay bricks as a construction element, from a set of small-scale production brickyards, located in the north of the department of Valle del Cauca - Colombia, in relation to the quality parameters established in the Colombian Technical Standard (NTC 4205), through the evaluation of the physical properties and mechanical, among which we have the determination of mass, modulus of rupture, compressive strength, water absorption, size measurement, and warping measurement; based on the guidelines established by the Colombian Technical Standard (NTC 4017). modulus of rupture, compressive strength, water absorption, size measurement, and warpage measurement; based on the guidelines established by the Colombian Technical Standard (NTC 4017). modulus of rupture, compressive strength, water absorption, size measurement, and warpage measurement; based on the guidelines established by the Colombian Technical Standard (NTC 4017).

Keywords: clay bricks, Colombian Technical Standard, construction materials.

1. INTRODUCTION

Civil engineering has a notable impact on the economic and social development of a community, through the proposal of construction processes and the implementation of resistant and efficient materials, which allow transforming the environment in the constant search to improve the quality of life of the society.

The various areas that make up this discipline, such as structures, geotechnics, hydraulics, among others, promote different construction systems that put into practice a wealth of knowledge that is involved and forms part of the design, construction, and maintenance of the infrastructures carried out in the engineering field. The structures that make up a construction project must be able to withstand impact loads and also comply with the functionality that governs the design of the building. In this sense, the walls as a construction element in their structural function allow the division of spaces and the transfer of forces to other elements to achieve stability. For the formation of walls, whether structural or non-structural, there are different elements,

The construction sector is one of the biggest drivers of the economy in Colombia, it is considered a driver of growth and national development [1]; By consolidating this sector, it incurs benefits in the country's Gross Domestic Product (GDP), which represents the possibility for thousands of citizens and companies to invest in housing or profitable spaces dedicated to commerce and entrepreneurship. Currently, the constructions carried out in Colombia use a great diversity of construction materials for the elaboration of walls, such as clay bricks, concrete bricks, reinforced concrete walls, structural steel panels with polyurethane, among others, which are selected based on the physical characteristics of the building, the geographical environment, availability, as well as the cost and time of the construction process.

The coffee zone of Colombia stands out for having areas with high concentrations of clay brick producers, characterized by the manufacture of multiple types of these elements, among which we have Adobe, Perforated, Solid, Tiled, Normalized, Hollow, Refractory, Decorative, for the floor. An example of this is the northern area of the department of Valle del Cauca, where various towns concentrate their economy on this activity, these towns use manufacturing processes that range from artisanal techniques to processes. already standardized. Bricks as a construction element have developed along with humanity, it is affirmed that, in the Paleolithic age, in the year 9000 BC they were already used, entering to a certain extent to the decoration; on the other hand, in Babylon, it was used to reinforce its constructions and cover its walls and ramparts. The first was made of adobe burned and dried in the sun. They had multiple forms and dimensions, which were changing over time. [2]. The brick is manufactured using clay compounds, in addition to silicates of alumina, kaolin, and different minerals. This mixture is emptied into rectangular prismatic molds, the same as the bricks will be, and then they are subjected to drying and firing.

In European areas such as Germany, England, and the Netherlands, brick has been highly appreciated, they used it in small homes as well as palaces and castles. Today it maintains its validity, in fact, it has been given a preponderant role in works of a contemporary nature. All this is due to its high resistance in large structures, likewise, it has qualities that allow you to enjoy cool places in hot climates and shelter when the weather is very cold; It is also highly durable and heat resistant. Clay brick has characteristics of durability and impermeability, it is a magnificent option for rural areas and the construction of dikes, as it prevents the passage of water through it.

Clay masonry units are characterized by having certain benefits compared to concrete bricks, among these benefits are their low density (60% lighter), low cost, savings of 50% in the construction of 1m2 among others [3].

According to the (NTC-4051) [4], clay is an aggregate material of mineral origin, of earthy or stony consistency, composed essentially of hydrated alumina silicates, capable of becoming plastic with the limited edition of water, rigid when dry, and stony when subjected to a sufficiently high temperature.

The main attributes of the real estate sector and the construction companies of houses, offices, shops, service centers, works, and other types of buildings, are the dynamism and the reactivating character that they contribute to the global economy.

From this perspective, it is important to emphasize that civil works must be capable of responding correctly to the established design requirements, both in terms of safety and economics, thus guaranteeing correct operation during their useful life.

Generally, Clay bricks are widely used in the engineering industry, in residential, commercial, and office buildings, among others; This is due to its multiple advantages, among which have its low production cost, its functionality as thermal and acoustic insulation, among others.

Clay bricks are used in masonry construction processes, specifically in walls. Walls can be defined as “vertical elements that are used to separate and close spaces” [5].

According to [6], the walls perform two functional roles: to form an envelope that provides safety and shelter from outside vision, wind, and rain, and to support the weight of the building's superstructure.

The National Association of Entrepreneurs of Colombia (ANDI) affirms that, in Colombia, the clay brick industry is heterogeneous in its composition, with a notorious level of informality.

According to the Corporate Environmental Corporation, in 2019, 25% of the tons of bricks in Colombia is produced by large industry in only 3% of the kilns, while the remaining 75% is produced in 97% of the bricks. ovens, which corroborates the high informality [7].

In a more particular case,97% of the brickyards in the Valle del Cauca region are mechanized, that is, they have Pampa-type kilns; while the remaining percentage is divided into small, medium, and large companies, which have Wagon, Hoffman, and Tunnel type furnaces respectively.[8].

For this reason, it is essential that the components of the structural elements of a construction project be able to withstand the different loads to which they will be exposed and, likewise, comply with the functionality that governs the design of the building.

This research aims to analyze the physical and mechanical properties of clay bricks manufactured in seven (7) brickyards in the northern area of the department of Valle del Cauca, Colombia; specifically the municipality of Cartago, and compare the results obtained with the parameters established in the Colombian Technical Standard for construction elements of clay masonry. This research aims to make a comparative diagnosis of the physical and mechanical properties of these bricks. carried out on specimens from brickyards located in the north of the department of Valle del Cauca (Colombia).

2. Experimental program

For the purposes of this research, two sample spaces were defined.[9]. The first sample space was related to the selection of the manufacturers that make clay bricks in the northern area of the department of Valle del Cauca (Colombia), specifically the municipality of Cartago, where the seven (7) selected brickyards are located. the extraction of the study specimens. Initially, 30 clay masonry units were acquired from each of the seven selected factories, for a total of 210 units, in order to perform the quality evaluation parameter tests described in the Colombian Technical Standard.

On the other hand, the following space was integrated by elements extracted from the population through simple random sampling, which defines the batches and the number of clay bricks subject to the experimentation process; Two types were selected: solid bricks and bricks with horizontal lantern-type perforation.

2.1. Characterization tests

In the experimental program of this research, the type of brick extracted from each of the brickyards is detailed, as well as the design dimensions for each brickyard.

Table1 *Design dimensions of clay brick units.*

brick type	*brickyard*	*Units*	*Dimensions (cm)*
Bricks with perforation horizontal smooth lantern type	brick D	30	10x20x30
	brickyard E	30	10x20x30
	brickyard F	30	10x20x30
	brickyard G	30	10x20x30
solid bricks	brickyard A	30	7x12x24
	brickyard B	30	6x12x26
	brickyard C	30	7x13x26.5

Note: Design dimensions for each of the brickyards under study. (Own source)

2.2. Characterization tests

For the characterization of these, the first sample space was related to the selection of manufacturers that make clay bricks in the northern area of the department of Valle del Cauca (Colombia), specifically the municipality of Cartago, where the seven (7) brickyards selected for the extraction of the study specimens. On the other hand, the following space was integrated by elements extracted from the population through simple random sampling, which defines the batches and the number of clay bricks subject to the experimentation process, two types were selected: solid bricks and solid bricks. with horizontal lantern type perforation. A series of laboratory tests were applied to the clay bricks that make up the sample under study,

These tests allowed for evaluation of the determination of mass, determination of size, determination of warping, water absorption, modulus of rupture, and resistance to compression, in the elements of the sample under study, generating results that intervene in the process of comparison and development of the pertinent analysis, which considers as a reference the regulations related to the design requirements of this structural element.

Tests were carried out on bricks with horizontal perforation, from Ladrillera D, Ladrillera E, Ladrillera F, and Ladrillera G, based on (NTC-4017)[10]; WatchTable 2.

Table 2 *Tests to carry out on the masonry units.*

Selected Parameter	***Applicable standard***
Sampling	NTC-4017 Number 4
Determination of mass	NTC-4017 Number 5
Modulus of rupture (flexural test)	NTC-4017 Number 6
compressive strength	NTC-4017 Number 7
Water absorption	NTC-4017 Number 8
size measurement	NTC-4017 Number 12
Warp Measurement	NTC-4017 Number 13

Note: Tests that will be carried out on clay brick samples for their quality evaluation. (Own source).

Initially, 30 clay masonry units were purchased from each of the seven selected factories, for a total of 210 units, in order to perform the quality evaluation parameter tests described in the Colombian Technical Standard. In the table 1the type of brick extracted from each of the brickyards is detailed, as well as the design dimensions for each brickyard.

2.3. Methodology

The tests carried out by Ladrillera are detailed below.

Bearing in mind that, for bricks with horizontal perforation, the measurements are standard in all brickyards, as presented in table 1, dimensional tolerance and warping distortion tolerance on surfaces and edges, is the same for all the aforementioned samples. These tolerances are presented below:

Table 3 *Dimensional tolerance for clay bricks with horizontal perforation.*

Measure	***Design dimension (cm)***	***Dimensional tolerance (mm)***	***Tolerance range (cm)***
Width	10.0	3	9.7 – 10.3
High	20.0	4	19.6 – 20.4
Length	30.0	4	29.6 – 30.4

*Note:*Dimensional tolerance allowed by the Colombian Technical Standard regarding design dimensions for clay bricks. (Own source).

Table 4 *Distortion tolerance on the surfaces and edges of bricks with horizontal perforation.*

Measure	***warping on surfaces***		***Measure***	***warping at edges***	
	Design dimension (cm)	***Distortion tolerance (mm)***		***Design dimension (cm)***	***Distortion tolerance (mm)***
W x H	10.0x20.0	two	width	10.0	1
W x H	10.0 x 30.0	3	high	20.0	two
W x H	20.0 x 30.0	3	length	30.0	3

*Note:*Maximum distortion tolerance allowed by the Colombian Technical Standard for clay bricks (A: width, H: height). (Own source).

Brickyard D

When carrying out the mass determination process for each clay brick extracted from brickyard D, an average of 3817gr was obtained, and a standard deviation of 45.88gr.

The modulus of rupture of each brick from brickyard D was determined, obtaining a minimum value of modulus of rupture of 0.85 Pa, a maximum of 1.18 and an average of 1.05 Pa, the standard deviation presented by the results of the ten (10) tested bricks was 0.10 Pa see figure 1.

The compressive strength of each tested clay brick sample is calculated, and subsequently, the average is calculated for every 5 units, in order to compare with the minimum values required by the (NTC-4205).[eleven]and corroborate if the brickyard D complies with this quality parameter.

According to the tests carried out in the figure 3andFigure 4it is possible to observe that 60% of the bricks with horizontal perforation tested to comply with the minimum resistance to compression per unit established for structural use, which is 3.5 MPa; on the other hand, 100% of the tested bricks with horizontal perforation meet the minimum compressive strength per unit established for non-structural use, which is 2.0 MPa.

Along the same lines, the two averages obtained for every 5 units tested (3.72 MPa and 4.08 MPa, respectively) do not meet the minimum strength required for structural use, which is 5 MPa; instead, the two averages obtained above meet the minimum strength required for non-structural use, which is 3 MPa.

In theFigure 5andFigure 6the results of the percentage of absorption of the samples with horizontal perforation tested are presented, It is observed that, for structural use, 100% of the bricks do not comply with the maximum absorption for interior use, and likewise, 100% of these bricks do not comply with the maximum absorption for exterior use; Regarding the averages determined for every 5 units (19.25% and 18.29% respectively), the samples present absorptions higher than those allowed for both interior (13%) and exterior (13.5%) uses.

Along the same lines, it is observed that, for non-structural use, 90% of the bricks comply with the maximum absorption for interior use and, on the contrary, 100% of these bricks do not comply with the maximum absorption for use in exteriors; Regarding the averages determined for every 5 units (19.25% and 18.29% respectively), the samples present absorptions higher than those allowed for both interior (17%) and exterior (13.5%) uses.

It is possible to determine that 70% of the clay bricks tested from brickyard D do not meet the dimensional tolerance established by (NTC-4205)[eleven]; that is, 21 of the 30 samples studied are below the measure of the minimum length determined in theTable 3. On the other hand, it is possible to determine that the greatest dimensional variation of the actual measurement compared to the design is the width, with a value of 2.75%.

Starting from theTable 4, regarding the distortion tolerance for surfaces, it is determined that 70% of the clay bricks tested from factory D do not meet the required distortion tolerance, that is, 7 of the 10 tested bricks have deviations in the surface greater than 1% of the design dimension.

For edge distortion tolerance, it is determined that 100% of the clay bricks tested from Factory D do not meet the required distortion tolerance, that is, the 10 bricks tested have edge deviations greater than 1% of the design dimension.

Brickyard E

When carrying out the mass determination process for each clay brick extracted from brickyard E, an average of 3813gr was obtained, and a standard deviation of 53.09gr.

The modulus of rupture of each brick from brickyard E was determined, obtaining a minimum value of modulus of rupture of 0.88 Pa, a maximum of 1.48 and an average of 1.21 Pa, the standard deviation presented by the results of the ten (10) tested bricks was 0.20 Pa see figure 1.

The compressive strength of each tested clay brick sample is calculated, and subsequently, the average is calculated for every 5 units, in order to compare with the minimum values required by the (NTC-4205).[eleven]and corroborate if brickyard E complies with this quality parameter.

According to tests carried out in the figure 3andFigure 4It is possible to observe that 40% of the tested bricks with horizontal perforation meet the minimum compressive strength per unit established for structural use, which is 3.5 MPa; on the other hand, 100% of the tested bricks with horizontal perforation meet the minimum compressive strength per unit established for non-structural use, which is 2.0 MPa.

Along the same lines, the two averages obtained for every 5 units tested (3.75 MPa and 3.33 MPa, respectively) do not meet the minimum strength required for structural use, which is 5 MPa; instead, the two averages obtained above meet the minimum strength required for non-structural use, which is 3 MPa.

In theFigure 5andFigure 6the results of the percentage of absorption of the samples with horizontal perforation tested are presented, where it is observed that, for structural use, 100% of the bricks do not comply with the maximum absorption for interior use, and likewise, 100% of these bricks do not comply with the maximum absorption for exterior use; Regarding the averages determined for every 5 units (18.57% and 18.55% respectively), the samples present absorptions higher than those allowed for both interior (13%) and exterior (13.5%) uses.

Along the same lines, it is observed that, for non-structural use, 90% of the bricks meet the maximum absorption for indoor use, also, 100% of these bricks do not meet the maximum absorption for outdoor use; Regarding the averages determined for every 5 units (18.57% and 18.55% respectively), the samples present absorptions higher than those allowed for both interior (17%) and exterior (13.5%) uses.

It is possible to determine that 67% of the clay bricks tested from brickyard E do not meet the dimensional tolerance established by (NTC-4205)[eleven]; that is, 20 of the 30 samples studied are below the measure of the minimum length determined in theTable 3. On the other hand, it is possible to determine that the greatest dimensional variation of the actual measurement compared to the design is the width, with a value of 5.00%.

Starting from theTable 4, regarding the distortion tolerance for surfaces, it is determined that 40% of the tested clay bricks from factory E do not meet the required distortion tolerance, that is, 4 of the 10 tested bricks have deviations in the surface greater than 1% of the design dimension.

For edge distortion tolerance, it is determined that 100% of the clay bricks tested from factory E do not meet the required distortion tolerance, that is, the 10 bricks tested have edge deviations greater than 1% of the design dimension.

Brickyard F

When carrying out the mass determination process for each clay brick extracted from brickyard F, an average of 3826gr was obtained, and a standard deviation of 54.36gr.

The modulus of rupture of each brick from brickyard F was determined, obtaining a minimum value of modulus of rupture of 0.88 Pa, a maximum of 1.52 and an average of 1.26 Pa, the standard deviation presented by the results of the ten (10) tested bricks was 0.18 Pa see figure 1.

The compressive strength of each tested clay brick sample is calculated, and subsequently, the average is calculated for every 5 units, in order to compare with the minimum values required by the (NTC-4205).[eleven]and corroborate if the brickyard F complies with this quality parameter.

According to tests carried out in the figure 3andFigure 4It is possible to observe that 70% of the bricks with horizontal perforation tested to meet the minimum compressive strength per unit established for structural use, which is 3.5 MPa; on the other hand, 100% of the tested bricks with horizontal perforation meet the minimum compressive strength per unit established for non-structural use, which is 2.0 MPa.

Along the same lines, the two averages obtained for every 5 units (3.80 MPa and 3.82 MPa, respectively) tested do not meet the minimum strength required for structural use, which is 5 MPa; instead, the two averages obtained above meet the minimum strength required for non-structural use, which is 3 MPa.

In theFigure 5andFigure 6the results of the percentage of absorption of the samples with horizontal perforation tested are presented, where it is observed that, for structural use, 100% of the bricks do not comply with the maximum absorption for interior use, and likewise, 100% of these bricks do not comply with the maximum absorption for exterior use; Regarding the averages determined for every 5 units (18.66% and 18.35% respectively), the samples present absorptions higher than those allowed for both interior (13%) and exterior (13.5%) uses.

Along the same lines, it is observed that, for non-structural use, 100% of the bricks meet the maximum absorption for indoor use, also, 100% of these bricks do not meet the maximum absorption for outdoor use; Regarding the averages determined for every 5 units (18.66% and 18.35% respectively), the samples present absorptions higher than those allowed for both interior (17%) and exterior (13.5%) uses.

It is possible to determine that 60% of the clay bricks tested from brickyard F do not meet the dimensional tolerance established by (NTC-4205)[eleven]; that is, 18 of the 30 samples studied are below the measure of the minimum length determined in theTable 3. On the other hand, it is possible to determine that the greatest dimensional variation of the actual measurement compared to the design is the length, with a value of 4.17%.

Starting from theTable 4, regarding the distortion tolerance for surfaces, it is determined that 70% of the tested clay bricks from factory F do not meet the required distortion tolerance, that is, 7 of the 10 tested bricks have deviations in the surface greater than 1% of the design dimension.

For edge distortion tolerance,it is determined that 100% of the tested clay bricks from factory F do not meet the required distortion tolerance, that is, the 10 tested bricks have edge deviations greater than 1% of the design dimension.

Brickyard G

When carrying out the mass determination process for each clay brick extracted from brickyard G, an average of 3801gr was obtained, and a standard deviation of 53.52gr.

The modulus of rupture of each brick from brickyard G was determined, obtaining a minimum value of modulus of rupture of 1.10 Pa, a maximum of 1.57 and an average of 1.28 Pa, the standard deviation presented by the results of the ten (10) tested bricks was 0.16 Pa see figure 1.

The compressive strength of each tested clay brick sample is calculated, and subsequently, the average is calculated for every 5 units, in order to compare with the minimum values required by the (NTC-4205).[eleven]and corroborate if the brick G complies with this quality parameter.

According to tests carried out in the figure 3andFigure 4It is possible to observe that 50% of the tested bricks with horizontal perforation meet the minimum compressive strength per unit established for structural use, which is 3.5 MPa; on the other hand, 100% of the tested bricks with horizontal perforation meet the minimum compressive strength per unit established for non-structural use, which is 2.0 MPa.

Along the same lines, the two averages obtained for every 5 units tested (3.68 MPa and 3.88 MPa, respectively) do not meet the minimum strength required for structural use, which is 5 MPa; instead, the two averages obtained above meet the minimum strength required for non-structural use, which is 3 MPa.

In theFigure 5andFigure 6the results of the percentage of absorption of the samples with horizontal perforation tested are presented, where it is observed that, for structural use, 100% of the bricks do not comply with the maximum absorption for interior use, and likewise, 100% of these bricks do not comply with the maximum absorption for exterior use; Regarding the averages determined for every 5 units (18.75% and 18.93% respectively), the samples present absorptions higher than those allowed for both interior (13%) and exterior (13.5%) uses.

Along the same lines, it is observed that, for non-structural use, 100% of the bricks meet the maximum absorption for indoor use, also, 100% of these bricks do not meet the maximum absorption for outdoor use; Regarding the averages determined for every 5 units (18.75% and 18.93% respectively), the samples present absorptions higher than those allowed for both interior (17%) and exterior (13.5%) uses.

It is possible to determine that 63% of the clay bricks tested from brickyard G do not meet the dimensional tolerance established by (NTC-4205)[eleven]; that is, 19 of the 30 samples studied are below the measure of the minimum length determined in theTable 3. On the other hand, it is possible to determine that the greatest dimensional variation of the actual measurement compared to the design is the length, with a value of 4.67%.

Starting from theTable 4, regarding the distortion tolerance for surfaces, it is determined that 80% of the tested clay bricks from factory G do not meet the required distortion tolerance, that is, 8 of the 10 tested bricks have deviations in the surface greater than 1% of the design dimension.

For edge distortion tolerance, it is determined that 100% of the tested clay bricks from factory G do not meet the required distortion tolerance, that is, the 10 tested bricks have edge deviations greater than 1% of the design dimension.

Brickyard A

When carrying out the process of determining the mass for each clay brick extracted from Ladrillera A, an average of 3041gr was obtained, and a standard deviation of 39.74gr, the dispersion of the results obtained in the measurements of the masses of each sample tested.

The modulus of rupture of each brick from brickyard A is calculated, obtaining a minimum value of 0.49 Pa, a maximum of 1.36 Pa and an average of 0.77 Pa, the standard deviation presented by the results of the ten (10) tested bricks. was 0.28 Pa see figure 1.

The compressive strength of each tested clay brick sample is calculated, and subsequently, the average is calculated for every 5 units, in order to compare with the minimum values required by the (NTC-4205).[eleven]and corroborate whether brickyard A meets this quality parameter.

According to tests carried out in the figure, 3andFigure 4It is possible to observe that 60% of the solid type bricks tested meet the minimum compressive strength per unit established for structural use, which is 15.0 MPa; On the other hand, 100% of the solid-type bricks tested to meet the minimum compressive strength per unit established for non-structural use, which is 10.0 MPa.

Along the same lines, the two averages obtained for every 5 units tested (15.36 MPa and 415.64 MPa, respectively) do not meet the minimum strength required for structural use, which is 20.0 MPa; instead, the two averages obtained previously meet the minimum strength required for non-structural use, which is 14 MPa.

In theFigure 5andFigure 6the results of the absorption percentage of the solid-type samples tested are presented, where it is observed that, for structural use, 90% of the bricks do not meet the maximum absorption for interior use, and likewise, 100% of these bricks do not meet the maximum absorption for exterior use; Regarding the averages determined for every 5 units (17.05% and 18.56% respectively), the samples present absorptions higher than those allowed for both interior (13%) and exterior (13.5%) uses.

Along the same lines, it is observed that, for non-structural use, 100% of the bricks meet the maximum absorption for indoor use, also, 100% of these bricks do not meet the maximum absorption for outdoor use; Regarding the averages determined for every 5 units (17.05% and 18.56%% respectively), the samples present absorptions higher than those allowed for both interior (17%) and exterior (13.5%) uses.

Bearing in mind that, for solid-type bricks, the design dimensions are different, as presented in table 1, next, the dimensional tolerance is presented for brick A.

Table 5 *Dimensional tolerance for solid-type clay bricks extracted from the Ladrillera A factory.*

Measure	***Design dimension (cm)***	***Dimensional tolerance (mm)***	***Tolerance range (cm)***
Width	7.0	two	6.8 – 7.2
High	12.0	3	11.7 – 12.3
Length	24.0	4	23.6 – 24.4

Note: Dimensional tolerance allowed by the Colombian Technical Standard regarding design dimensions for clay bricks. (Own source).

It is possible to determine that 40% of the clay bricks tested from brickyard A do not meet the dimensional tolerance established by (NTC-4205)[eleven]; that is, 12 of the 30 samples studied are below the measure of the minimum length determined in theTable 5. On the other hand, it is possible to determine that the greatest dimensional variation of the actual measurement compared to the design is the width, with a value of 4.29%.

Bearing in mind that, for solid-type bricks, the design dimensions are different, as presented in table 1, next, the warping distortion tolerance on surfaces and edges is presented for brick A.

Table 6 *Warping distortion tolerance in solid-type clay bricks extracted from the Ladrillera A factory.*

Measure	***warping on surfaces***		***Measur e***	***warping at edges***	
	Design dimension (cm)	***Distortion tolerance (mm)***		***Design dimension (cm)***	***Distortion tolerance (mm)***
W x H	7.0x12.0	1	Width	7.0	1
W x H	7.0 x 24.0	two	High	12.0	1
W x H	12.0 x 24.0	two	Length	24.0	two

Note: Maximum distortion tolerance allowed by the Colombian Technical Standard for clay bricks (A: width, H: height). (Own source).

Starting from theTable 6, regarding the distortion tolerance for surfaces, it is determined that 90% of the tested clay bricks from factory A do not meet the required distortion tolerance, that is, 9 of the 10 tested bricks have deviations in the surface greater than 1% of the design dimension.

For edge distortion tolerance, It is determined that 100% of the clay bricks tested from Factory A do not meet the required distortion tolerance, that is, the 10 bricks tested have edge deviations greater than 1% of the design dimension.

Brickyard B

When carrying out the process of determining the mass for each clay brick extracted from Ladrillera B, an average of 2885gr was obtained, and a standard deviation of 54.34gr, the dispersion of the results obtained in the measurements of the masses of clay is presented. each sample tested.

The modulus of rupture of each brick from brickyard B is calculated, obtaining a minimum value of 0.77 Pa, a maximum of 1.58 Pa and an average of 1.23 Pa, the standard deviation presented by the results of the ten (10) tested bricks. was 0.24 Pa see figure 1.

The compressive strength of each tested clay brick sample is calculated, and subsequently, the average is calculated for every 5 units, in order to compare with the minimum values required by the (NTC-4205).[eleven]and corroborate if the brickyard B complies with this quality parameter.

According to tests carried out in the figure, 3andFigure 4It is possible to observe that 50% of the solid type bricks tested meet the minimum compressive strength per unit established for structural use, which is 15.0 MPa; On the other hand, 100% of the solid-type bricks tested to meet the minimum compressive strength per unit established for non-structural use, which is 10.0 MPa.

Along the same lines, the two averages obtained for every 5 units tested (15.05 MPa and 16.31 MPa, respectively) do not meet the minimum strength required for structural use, which is 20.0 MPa; instead, the two averages obtained previously meet the minimum strength required for non-structural use, which is 14 MPa.

In theFigure 5andFigure 6the results of the absorption percentage of the solid-type samples tested are presented, where it is observed that, for structural use, 80% of the bricks do not meet the maximum absorption for indoor use, and likewise, 90% of these bricks do not meet the maximum absorption for outdoor use either; Regarding the averages determined for every 5 units (18.29% and 17.23% respectively), the samples present absorptions higher than those allowed for both interior (13%) and exterior (13.5%) uses.

Along the same lines, it is observed that, for non-structural use, 90% of the bricks meet the maximum absorption for indoor use, also, 90% of these bricks do not meet the maximum absorption for outdoor use; Regarding the averages determined for every 5 units (18.29% and 17.23% respectively), the samples present absorptions higher than those allowed for both interior (17%) and exterior (13.5%) uses.

Bearing in mind that, for solid-type bricks, the design dimensions are different, as presented in theTable 1, next, the dimensional tolerance for brick B is presented.

Table 7 *Dimensional tolerance for solid-type clay bricks extracted from Ladrillera B.*

Measure	***Design dimension (cm)***	***Dimensional tolerance (mm)***	***Tolerance range (cm)***
Width	6.0	two	5.8 – 6.2
High	12.0	3	11.7 – 12.3
Length	26.0	4	25.6 – 26.4

Note: Dimensional tolerance allowed by the Colombian Technical Standard regarding design dimensions for clay bricks. (Own source).

It is possible to determine that 80% of the clay bricks tested from brickyard B do not meet the dimensional tolerance established by (NTC-4205)[eleven]; that is, 24 of the 30 samples studied are below the measure of the minimum length determined in theTable 7. On the other hand, it is possible to determine that the greatest dimensional variation of the actual measurement compared to the design is the height, with a value of 4.58%.

Bearing in mind that, for solid-type bricks, the design dimensions are different, as presented in the table 1, next, the warping distortion tolerance on surfaces and edges is presented for brick B.

Table 8 *Warping distortion tolerance in solid-type clay bricks extracted from Ladrillera B.*

Measure	***warping on surfaces***		***Measure***	***warping at edges***	
	Design dimension (cm)	***Distortion tolerance (mm)***		***Design dimension (cm)***	***Distortion tolerance (mm)***
W x H	6.0x12.0	1	Width	7.0	1
W x H	6.0x26.0	3	High	12.0	1
W x H	12.0x26.0	3	Length	24.0	3

Note: Maximum distortion tolerance allowed by the Colombian Technical Standard for clay bricks (A: width, H: height). (Own source).

Starting from theTable 8, regarding the distortion tolerance for surfaces, it is determined that 100% of the tested clay bricks from factory B do not meet the required distortion tolerance, that is, 10 of the 10 tested bricks have deviations in the surface greater than 1% of the design dimension.

For edge distortion tolerance,It is determined that 100% of the clay bricks tested from factory B do not meet the required distortion tolerance, that is, the 10 bricks tested have edge deviations greater than 1% of the design dimension.

Brickyard C

When carrying out the process of determining the mass for each clay brick extracted from Ladrillera C, an average of 3213gr was obtained, and a standard deviation of 48.31gr, the dispersion of the results obtained in the measurements of the masses of clay is presented. each sample tested.

The modulus of rupture of each brick from brickyard C is calculated, obtaining a minimum value of 0.48 Pa, a maximum of 1.22 Pa and an average of 1.22 Pa, the standard deviation presented by the results of the ten (10) tested bricks. was 0.24 Pa see figure 1.

The compressive strength of each tested clay brick sample is calculated, and subsequently, the average is calculated for every 5 units, in order to compare with the minimum values required by the (NTC-4205).[eleven]and corroborate whether brick C complies with this quality parameter.

According to tests carried out in figure, 3 and Figure 4 It is possible to observe that 30% of the solid type bricks tested to meet the minimum compressive strength per unit established for structural use, which is 15.0 MPa; On the other hand, 100% of the solid-type bricks tested to meet the minimum compressive strength per unit established for non-structural use, which is 10.0 MPa.

Along the same lines, the two averages obtained for every 5 units tested (14.29 MPa and 14.20 MPa, respectively) do not meet the minimum strength required for structural use, which is 20.0 MPa; instead, the two averages obtained previously meet the minimum strength required for non-structural use, which is 14 MPa.

In the Figure 5andFigure 6the results of the absorption percentage of the solid-type samples tested are presented, where it is observed that, for structural use, 80% of the bricks do not meet the maximum absorption for interior use, and likewise, 100% of these bricks do not meet the maximum absorption for exterior use; Regarding the averages determined for every 5 units (17.49% and 17.1% respectively), the samples present absorptions higher than those allowed for both interior (13%) and exterior (13.5%) uses.

Along the same lines, it is observed that, for non-structural use, 100% of the bricks meet the maximum absorption for indoor use, also, 100% of these bricks do not meet the maximum absorption for outdoor use; Regarding the averages determined for every 5 units (17.49% and 17.1% respectively), the samples present absorptions higher than those allowed for both interior (17%) and exterior (13.5%) uses.

Bearing in mind that, for solid-type bricks, the design dimensions are different, as presented in theTable 1, next, the dimensional tolerance for brick C is presented.

Table 9 *Dimensional tolerance for solid-type clay bricks extracted from Ladrillera C.*

Measure	***Design dimension (cm)***	***Dimensional tolerance (mm)***	***Tolerance range (cm)***
Width	7.0	two	6.8 – 7.2
High	13.0	3	12.7 – 13.3
Length	26.5	4	26.1 – 26.9

Note: Dimensional tolerance allowed by the Colombian Technical Standard regarding design dimensions for clay bricks. (Own source).

It is possible to determine that 47% of the clay bricks tested from brickyard C do not meet the dimensional tolerance established by (NTC-4205)[eleven]; that is, 14 of the 30 samples studied are below the measure of the minimum length determined in theTable 9. On the other hand, it is possible to determine that the greatest dimensional variation of the actual measurement compared to the design is the height, with a value of 5.36%.

Bearing in mind that, for solid-type bricks, the design dimensions are different, as presented in theTable 1, next, the warping distortion tolerance on surfaces and edges is presented for brick C.

Table 10 *Warping distortion tolerance in solid-type clay bricks extracted from Ladrillera C.*

Measure	***warping on surfaces***		***Measure***	***warping at edges***	
	Design dimension (cm)	***Distortion tolerance (mm)***		***Design dimension (cm)***	***Distortion tolerance (mm)***
W x H	7.0x13.0	1	Width	7.0	1
W x H	7.0x26.5	3	High	12.0	1
W x H	13.0x26.5	3	Length	24.0	3

Note: Maximum distortion tolerance allowed by the Colombian Technical Standard for clay bricks (A: width, H: height). (Own source).

Starting from the Table 10, regarding the distortion tolerance for surfaces, it is determined that 100% of the tested clay bricks from factory C do not meet the required distortion tolerance, that is, 10 of the 10 tested bricks have deviations in the surface greater than 1% of the design dimension.

For edge distortion tolerance, It is determined that 100% of the clay bricks tested from factory C do not meet the required distortion tolerance, that is, the 10 bricks tested have edge deviations greater than 1% of the design dimension.

3. Analysis of results

According the results obtained in the different tests, it is summarized starting from the (NTC-4205)[eleven], the compliance of each of the brickyards in terms of the values established for each of the parameters.

Along the same lines, because the Colombian Technical Standard does not establish values for compliance in terms of the properties of modulus of rupture and determination of mass, the summary of the averages of the values obtained in the tests is presented below. of said properties for each of the brickyards.

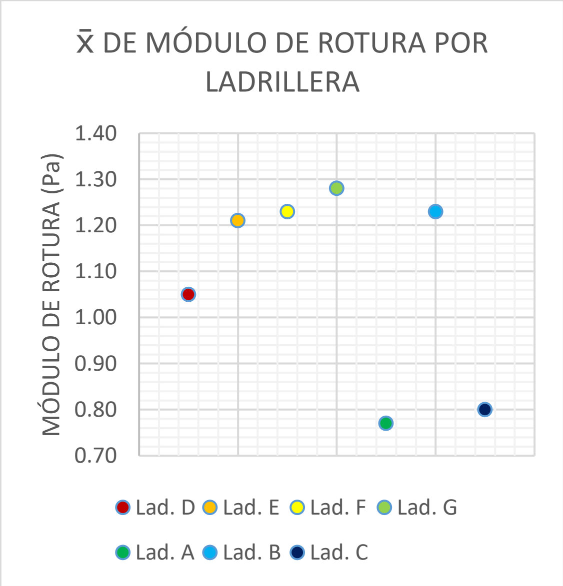

Figure1. *Averages of modulus of rupture were obtained by the samples of the brickyards tested. (Own source).*

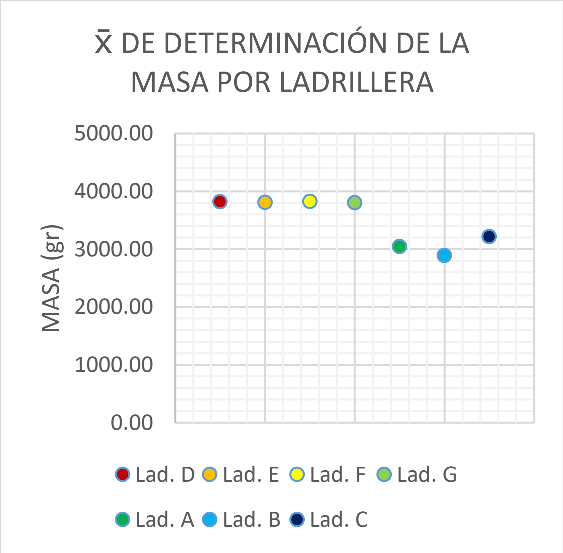

Figure 2. *Average determination of the mass obtained by the samples of the brickyards tested. (Own source).*

In the table, 11andTable 12compliance percentages are presented based on (NTC 4205)[eleven]both for the absorption and compressive strength parameters as well as for the dimensional measurement and warping measurement of the tested samples.

Table 11 *Percentages of compliance with the Colombian Technical Standard (NTC 4205) of the absorption and compressive strength parameters of the tested samples*.

brickyard	**Absorption**				**compressive strength**	
	structural use		**non-structural use**		**structural use**	**non-structural use**
	Inside	**Exterior**	**Inside**	**Exterior**		
The D. D	0%	0%	90%	0%	60%	100%
The D. AND	0%	0%	90%	0%	40%	100%
The D. F	0%	0%	100%	0%	70%	100%
The D. G	0%	0%	100%	0%	fifty%	100%
The D. TO	10%	0%	100%	0%	60%	100%
The D. B.	twenty%	10%	90%	10%	fifty%	100%
The D. C	twenty%	0%	100%	0%	30%	100%

Note:The percentages of compliance with the Colombian Technical Standard (NTC 4205) of the quality parameters (absorption and compressive strength) by the samples extracted from each brick kiln under study are presented.

Table 12 *Percentages of compliance with the Colombian Technical Standard (NTC 4205) of the dimensional measurement parameters and warpage measurement of the tested samples.*

brickyard	**dimension measurement**	**warping on surfaces**	**warping at edges**
The D. D	30%	30%	0%
The D. AND	33%	60%	10%
The D. F	40%	30%	0%
The D. G	37%	twenty%	0%
The D. TO	60%	10%	0%
The D. B.	twenty%	0%	0%
The D. C	53%	0%	0%

Note: The percentages of compliance with the Colombian Technical Standard (NTC 4205) of the quality parameters (absorption and compressive strength) by the samples extracted from each brick kiln under study are presented.

In the Figure 3 and Figure 4The General results obtained in the compressive strength, test are presented for each of the tested samples.

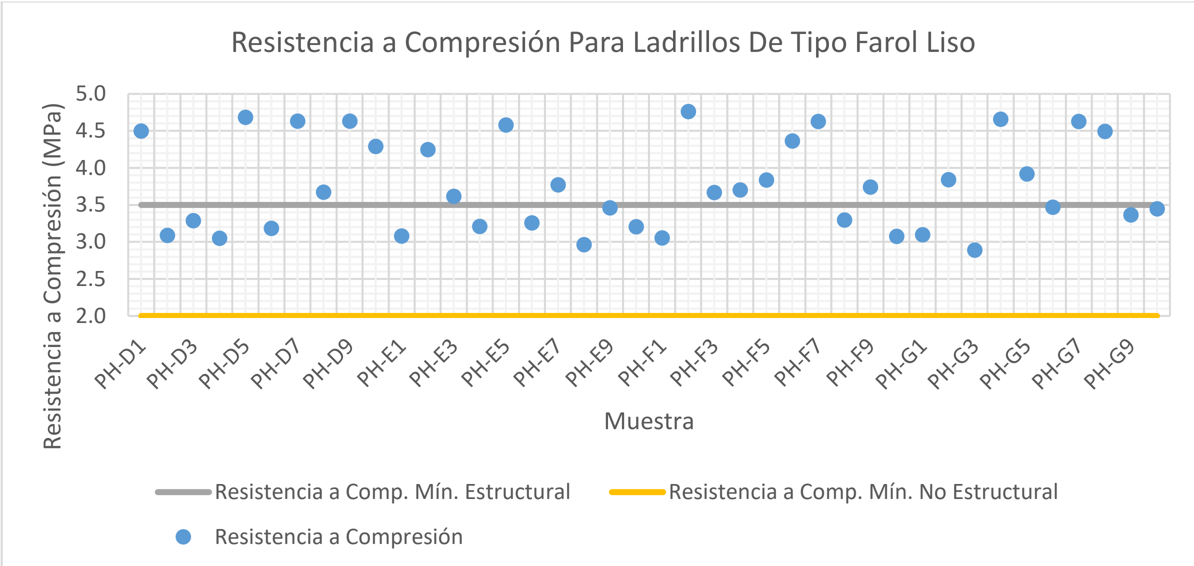

Figure 3. *Compressive strength of each tested brick sample with horizontal perforation. (Own source)*

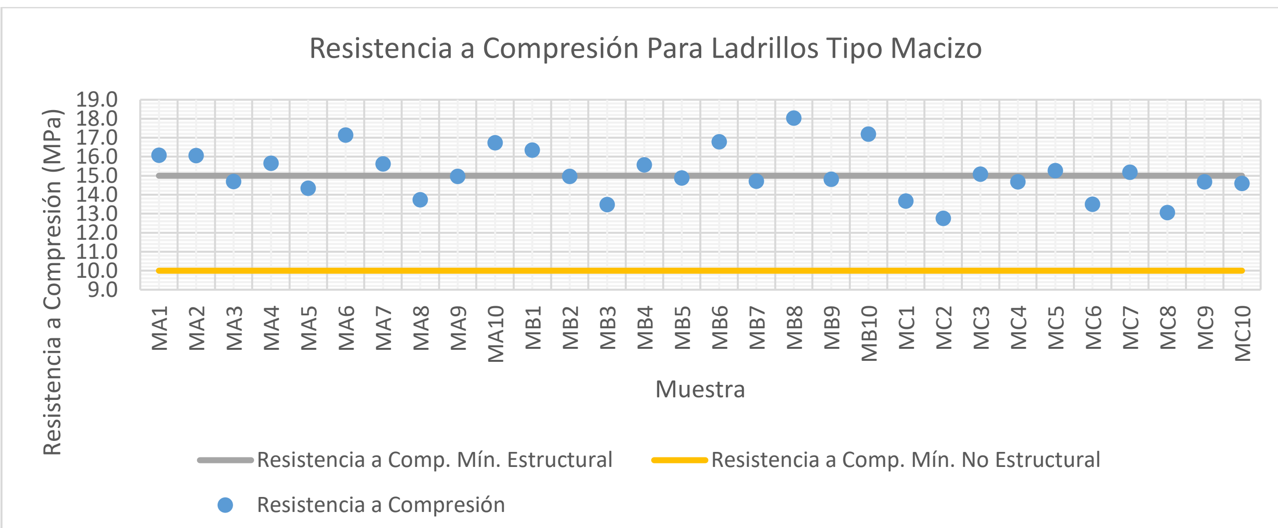

Figure 4. *Compressive strength of each solid type brick sample tested. (Own source).*

Then in figure 5 and the figure 6 The results obtained in the water absorption test are presented for each of the tested samples.

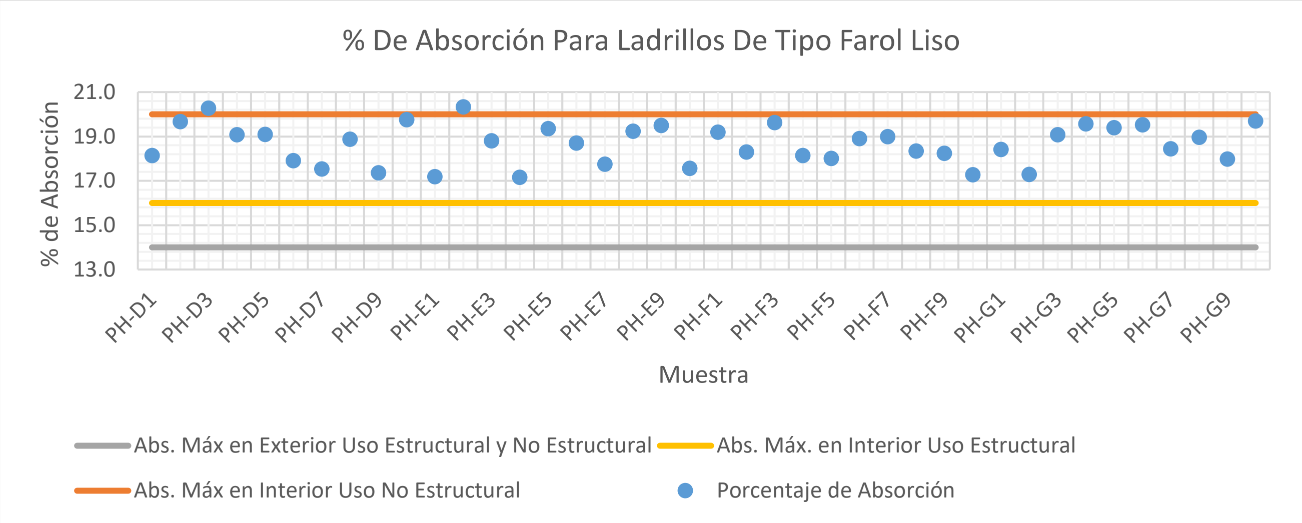

Figure 5. *Water absorption of each brick sample with horizontal perforation was tested. (Own source).*

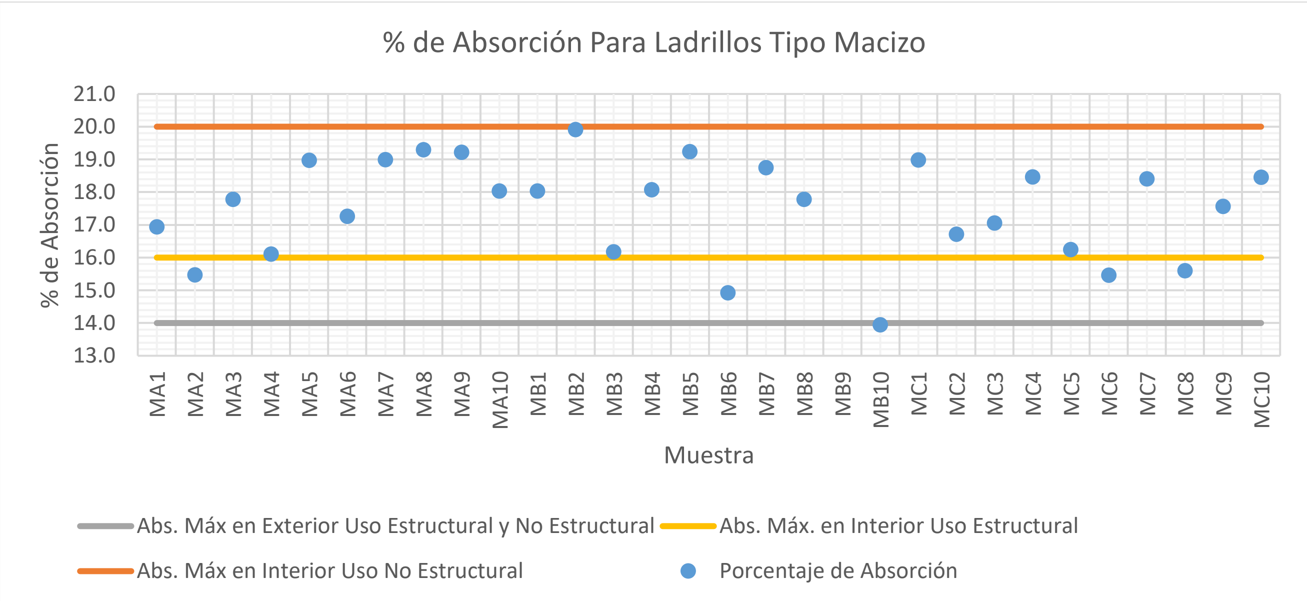

Figure 6. *Water absorption of each solid brick sample was tested. (Own source).*

Conclusions and recommendations

Taking into account the values established by the Colombian Technical Standard for each of the parameters evaluated and, based on the results obtained for the compressive strength, it was possible to establish that for structural use none of the brick kilns understudy fully comply with this parameter, additionally, very dispersed values were obtained among themselves; However, for non-structural use, we found that 100% of the tested bricks meet the minimum established values.

Along the same lines, in terms of the results obtained in the absorption tests, for structural use both indoors and outdoors, and for non-structural use outdoors, the samples show absorption values much higher than the maximums required by the Standard, it is also evident that the highest percentage of compliance was only 20% belonging to solid type bricks; for non-structural use, a better behavior was observed for the samples, experiencing compliance percentages that vary between 90% and 100%.

For the dimensional and warping analysis both on the surface and on the edges of the clay bricks, very scattered results were obtained, in which no sample from the different brickyards understudy fully complied with the maximum percentage of deviation established by the Colombian Technical Standard for said samples. The most critical case is presented by the physical property of edge warping, since only the brickyard E factory complied with this requirement by 10%, as for the rest of the factories, none of their samples complied with this parameter.

Finally, when performing the modulus of rupture test, very low-stress values were obtained, ranging from 0.77 MPa to 1.28 MPa, the most dispersed values being presented by solid-type clay bricks.

For purposes of transporting the masonry units, it is recommended to protect the batches of samples, in order to reduce contact with external surfaces, and in turn the impacts on them.

If you want to implement the use of clay bricks in facades, the use of waterproofing is recommended, in order to avoid high absorption by outdoor surfaces exposed to rain.

Manufacturers of artisanal bricks in the area are recommended to standardize their manufacturing processes, in order to improve processes and achieve the minimum quality required by the Colombian Technical Standard (NTC 4205).

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