Analysis of Physical and Mechanical Properties of Mud Brick Enhanced with Asphalt Recycling

Análisis de las propiedades físicas y mecánicas del adobe con asfalto reciclado

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Abstract

Introduction— In this work we have carried out a physical and mechanical analysis of the improvement of the material of mud brick (in Colombia it is known as "Adobe") with recycled asphalt.

Objective— Evaluate in the laboratory, the behavior of the material of mud brick with the addition of recycled asphalt.

Methodology— In order to meet the objective, quantitative research was conducted to characterize the physical evidence by analysis of particle size and density. The same tests characterize the mechanical strength in mud brick blocks, built with zero, two, four and eight percent recycled asphalt doses. It is based on laboratory testing.

Results— According to the results obtained in the tests, mechanical properties, such as resistance to compression and bending were improve, adding recycled asphalt to Mud brick and in comparison with samples without content of asphalt.

Conclusions— The mud bricks stabilized with two percent of recycled asphalt have the best performance in compressive and flexural strength according to laboratory testing.

Keywords— Mechanical strength; structural behavior; Sustainable construction material; buildings of earth; recycled asphalt; Mud bricks

Resumen

Introducción— En este trabajo se ha realizado un análisis físico y mecánico del mejoramiento del material de ladrillo de barro (en Colombia se conoce como "Adobe") con asfalto reciclado.

Objetivo— Evaluar en el laboratorio, el comportamiento del material de adobe con la adición de asfalto reciclado.

Metodología— Para cumplir con el objetivo, se realizó una investigación cuantitativa para caracterizar las pruebas físicas mediante el análisis de la granulometría y la densidad. Las mismas pruebas caracterizan la resistencia mecánica en bloques de ladrillo de barro, construidos con dosis de cero, dos, cuatro y ocho por ciento de asfalto reciclado. Se basa en pruebas de laboratorio.

Resultados— De acuerdo con los resultados obtenidos en los ensayos, las propiedades mecánicas, como la resistencia a la compresión y a la flexión fueron mejoradas, añadiendo asfalto reciclado a los ladrillos de barro y en comparación con las muestras sin contenido de asfalto.

Conclusiones— Los ladrillos de barro estabilizados con dos por ciento de asfalto reciclado tienen el mejor comportamiento en resistencia a la compresión y a la flexión según los ensayos de laboratorio.

Palabras clave— Resistencia mecánica; comportamiento estructural; material de construcción sostenible; edificios de tierra; asfalto reciclado; ladrillos de barro

I. Introduction

There are few studies on the behavior of historic structures of Mud brick and rammed earth in Latin America [1], which has contributed to the deterioration of these buildings, which are part of our architectural and cultural heritage. Colombia has 90% of its heritage buildings made of earth and most of them are located in high and intermediate seismic risk zones. the use of earth building technics such as mud bricks, rammed earth and wattle and doub were bring from Spanish colonization in Colombia [2], [3], [4], and their use is broad for rural housing construction due to the easy attainment of raw materials [5], [6]. At present, thirty percent of the world's population, approximately 1.5 billion people, live in buildings made of earth raw. In the case of the undeveloped countries about fifty percent of their rural population and twenty percent of the urban population dwells in buildings of land [7]. This is the case of Peru and Turkey, who developed seismic standards for the use of this material [8], [9], [10], [11].

The Mud brick is generally referred in different appellations [12]. Scientifically, the term mud brick refers to a clay mix, silt (sand with finer aggregate), sand, and sometimes coarse aggregates such as gravel. To talk of the synthetic unbaked brick typology, terms "mud bricks 'or "Adobe in Colombia' are usually engaged. Describing the compressed raw earth bricks, the term 'soil blocks' is commonly used.

To the media unit of the National University of Colombia in the latest census conducted by the National Administrative Department of Statistics, DANE, about sixteen percent of homes have been built with this type of materials [13]. Some towns located in Cundinamarca, Boyacá and Cauca, among others, are characterized by having many of their constructions made with earthen material [14]. Nevertheless, the main demand for this material is given in rural housing in Colombia [15], because this projects are in difficult to access areas; the use of industrialized materials and skilled labor raises it difficult to achieve in this conditions; causing that in many of these houses do not meet the requirements of earthquake resistance and even more that earth construction techniques are not specific including in the construction earthquake resistant code of Colombian like Seismic Standard (NSR).

On the other hand, and according to the figures of the Institute of Urban Development, only in Bogotá are estimated volumes of debris estimated at twelve billion trillion tons of civil works annually, of which approximately 10 percent correspond to composite debris Asphalt [16]. Therefore, it is necessary to reuse these materials in another type, reducing the waste of the same [17], [18]; also the implementation of these must demonstrate that they do not worsen the other material and on the contrary can lead to the improvement of the same.

One of the main axes of this investigation is the Mud brick, which is a material that by its nature has mechanical and structural limitations, requiring to be studied to certify the material as suitable for structural masonry; Offering better alternatives in the use of materials that can be reused, contributing economically and environmentally to the quality of life of the Colombian population.

The use of the soil is the basis of one of the technologies that best adapt to the environment and contemporary ways of conceiving sustainable construction. On the other hand, the impact of construction on the environment means that mankind is looking for alternatives to make the most of the resources offered by nature [19], especially given the current levels of pollution. Through the construction with raw this impact is diminished, since the alteration of the ecosystems is avoided [20].

This is the building material with the least ecological footprint and can be used without sophisticated training [20], which implies that it can be applied basically for the solution of housing demands. However, in spite of its insulating, inertial and resistant characteristics, the earth presents limitations in its application due to its mechanical resistance, vulnerability of humidity and erosion by the action of external agents. Due to the technological advance it has been proven that its mechanical properties before an earthquake do not have a good behavior [21]. Likewise, some research concludes that Mud brick constructions at component level, present structural and stability problems due to the brittleness in the joining of the blocks and the low resistance to the flexural stresses in the plane of the wall [22]. Other works quantify the influence that water content, clay percentage and fiber reinforcement produce on the mechanical performance of the tested Mud brick components [23].

The following is a summary of the main aspects to be taken into account in the manufacture of Mud brick, given that in Colombia the use of this material as a masonry element is not regulated, that is:

- The soil used should not contain pure clay due to its high drying shrinkage. The Technical Standard for Peruvian Edition NTE-E.080 in its section 4.1 specifies the following grading: sand in a range of 55% to 70%, slime between 15% and 25% and clay between 10% and 20%, not should be used organic. These ranges may vary when stabilized Mud brick is made [24].
- The soil is mixed with water, if there is not enough clay in a soil, it will not be strong enough when it dries. If there is not enough sand on the floor, it will shrink and crack when dry. A usual test for soil used to make Mud bricks, consist in to take a little mixture and to form with the hand about 5 or 6 balls of approximately 2 cm in diameter, once the balls are dry you should try to break them with 2 fingers of a hand, if the pellet is broken into large pieces then the soil is used for the preparation of Mud brick, if the admixture will crack is because contains a lot of sand; if it not and it is very moldable, is because it contains too much clay, therefore the admixture must be intermediate to this condition.

Once the material is selected the mixture is made with water and allowed to mature for three days to activate the clay, then prepare test Mud bricks, if the Mud bricks are cracked after 24 hours is because the soil has a lot of clay and Sand must be added. This preliminary test is important because it allows to find the appropriate mixture for the Mud bricks before beginning their production [24].

The Mud brick once prepared must be dried in the sun and used when completely dry, which occurs after approximately 20 days, depending on the weather conditions of the environment where they are prepared, if it is a very humid place or the site is Very cold, it will take longer to dry the mud brick with respect to dry environments and the summer sun [24].

II. Literature Review

A. *Asphalt recycled as stabilizer to improve mud bricks*

After mixing the soil with the diluted asphalt, it should be extended prior to use of the material in the manufacture of blocks to allow the solvent to evaporate [25]. It is best to mix the diluted asphalt with a small amount of soil, then mix it with the remaining soil. Asphalt emulsions are generally very fluid and mix readily with moist soil [26]. Excessive mixing should be avoided to prevent premature decomposition of the emulsion, leading to increased water absorption after drying. The emulsions must be diluted in the mixing water.

Soil mixes for compaction should not be too wet, so a smaller amount of stabilizer should be added [27]. The asphalt content should be 2% to 4%. Higher proportions produce dangerously low resistive pressures.

Similarly, in some research results [28], it is mentioned that asphalt-stabilized soil should be cured in dry air at a temperature of approximately 40°C, although asphalt stabilization does not improve soil strength, it does significantly reduce water absorption. In other words, although dry soil resistance is not very high, it is not reduced when wetted. The stabilization with asphalt is more effective in sandy and silty soils with a liquid limit between 25% and 35% and a plasticity index between 2.5% and 13%. The presence of acidic organic matter, sulfates and mineral salts can be very harmful. One possible remedy is to add 1% cement.

B. *Normative reference*

In the case of Colombia, there is still no complete standard to regulate the application of this type of construction techniques with Mud brick. "In the 2010 Resistant Earthquake Standard, known in the middle of construction as NSR-10, its use is regulated as long as it is combined with bamboo through the bahareque construction system" [29]. In 2005, the Colombian standard NTC-5324, published by ICONTEC (Colombian Institute of Technical Standards and Certification), is issued, being a translation of the French experimental norm XP P13-901,2001 of AFNOR (Association française de Normalization) on BTC (compressed earth blocks), which specifies the use for both walls and divisions, definitions, specifications, test methods and delivery conditions of cement block and becomes the starting point for the formal development of this technique in the country [30].

In order to address the problem of seismic vulnerability of buildings on Colombian soil, entitled was carry out following test of density, compressive strength, bending and stress strain behavior [31], summarized in Table 1, allowing to characterize these materials and whose results are presented in Table 2.

Table 1. Standard Characteristic of material test.

Test description	Standard
Density.	ASTM C 642-97
Compression Strength.	NTC-4017
Compression Strength in walls.	NTC-3495
Behavior stress deformation to the compression of walls.	NTC-3495
Flexural strength in direction perpendicular to vertical joints.	NTC-4109
Flexural strength in direction perpendicular to horizontal joints.	NTC-4109
Traction strength in diagonal.	NTC-4109

Source: [31].

Table 2. Average values of mechanical characterization tests of materials for earth construction techniques in standard bricks and walls.

<table>
<tr><th>Material of bricks</th><th>Y PROM (Ton/m3)</th><th>Test</th><th>Average value (MPa)</th><th>Standard deviation (MPa)</th></tr>
<tr><td rowspan="6">Mud brick</td><td rowspan="3">Mud brick piece 1.82</td><td>Compression strength.</td><td>2.84</td><td>0.855</td></tr>
<tr><td>Flexural strength in piece Mud brick.</td><td>0.49</td><td>0.188</td></tr>
<tr><td>Compression resistance in walls of Mud brick.</td><td>1.1</td><td>0.256</td></tr>
<tr><td rowspan="3">Mud brick walls 1.78</td><td>Elastic module in walls of Mud brick (E).</td><td>98.1</td><td>35.9</td></tr>
<tr><td>Diagonal traction stress in walls of Mud brick.</td><td>0.028</td><td>0.008</td></tr>
<tr><td>Shear module (G).</td><td>27.4</td><td>10.6</td></tr>
<tr><td rowspan="4">Rammed earth walls</td><td rowspan="4">1.93</td><td>Compression resistance in rammed earth walls of Earth.</td><td>0.55</td><td>0.184</td></tr>
<tr><td>Elastic module in rammed earth wall.</td><td>66.6</td><td>31.2</td></tr>
<tr><td>Diagonal traction stress in walls in Earth.</td><td>0.037</td><td>0.014</td></tr>
<tr><td>Shear modulus (G).</td><td>31.2</td><td>13.0</td></tr>
</table>

Source: [31].

C. *Tests of Mud bricks characterization*

According to the bibliographic consultation, the following tests were carried out:

- *Sieve analysis*: The method consists in introducing the sample in the sieves placed one on top of the other with the dimensions of the meshes in decreasing order. At the end of the filtration, the residues of each sieve and of the arrival vessel are weighed, where the material is called “through” [32].
- *Densiometric analysis*: “After performing density measurements on individual pieces of Mud brick and on treaded walls of variable dimensions” [33, p. 49], the results presented in Table 3 were obtained.
- *Bending and compression tests*: In the tests of compression and bending to pieces of Mud brick, Mud brick walls and diagonal traction of walls, the results presented in Table 4 were found [33].

- *Compression tests for compressed Mud bricks*: Due to the lack of experimentation with the materials for the construction with earth, the lack of implementation of the NTC-5324 for blocks cement soil and the little regulation for these materials, realized tests of compression Simple, taking as reference one of the tests used to determine the resistance of bricks and other materials [20].

Table 3. Average values of densities for Mud bricks and rammed earth walls.

Specimen	Samples	ρ Average (kg/m3)
Mud brick piece	20	1790
Mud brick walls	5	1770
rammed earth walls	7	1930

Source: [33].

Table 4. Summary of material properties.

Test	Material	P (kg/m3)	Top Stress	σ Standard	Elastic Module	σ Standard
Diagonal Traction strength (MPa)	Mud brick	1770	0.8	0.009	45.9	6.52
	Earth trampled wall	1930	0.6	0.014	55.9	23.4
Compression strength (MPa)	Mud brick	1770	0.016	0.001	16.52	1.41
	Earth trampled wall	1930	0.023	0.029	29.52	2.82

Source: [33].

III. Methodology

The methodology consisted in the accomplishment of varied dosages of asphalt as stabilizing material in the manufacture of the Mud brick, to analyze its physical and mechanical properties verifying if its load capacity complies with the technical standards for use as masonry material.

Both for the identification of the components that confer to the Mud brick the best structural behavior, and for the knowledge of the proportion in which they must be mixed, laboratory techniques were followed that allowed the characterization of the material. For the manufacture of the mud blocks in Mud brick production batches of eight units were carried out and the dosages of the materials used are presented in Table 5.

It is important that the amount of water added in each production was variable and this depended on the following factors: soil moisture content, asphalt content and the desired consistency of the final mixture.

Table 5. Dosages used to manufacture of the samples tested.

Type of sample	Brick dimension	Dosages		
	Large, Width, High	Clay soil (kg)	Recycled Asphalt (kg)	Straw (kg)
Without Asphalt 0%	24 cm, 12 cm, 12 cm	70	0	1
Asphalt 2%		68.5	1.4	1
Asphalt 4%		67.5	2.8	1
Asphalt 8%		67	5.7	1

Source: Authors.

The process and materials used are described below.

a) *Preparation of the clay*: A test of consistency was made to the material extracted from the quarry, forming six balls of approximately 2 cm in diameter, after drying them were subjected to manual pressure and fractures of large pieces were observed, indicating the Convenience of the material to be used in the manufacture of Mud bricks.

b) *Preparation of recycled asphalt*: For the stabilization of the Mud brick it was mixed to the mud with different dosages of recycled asphalt which was previously crushed to reduce the size of its particles.

c) *Mixing of soil and asphalt*: Manually mixing the previously wetted soil and the asphalt, the amounts of water depend on the observed consistency of the mixture. At the time of mixing, greater consistency was observed in less time compared to the common mixture without asphalt.

d) *Addition of the straw*: Previously the selection of the straw was made which was chopped in lengths of approximately 5 cm and later added to the mixture gradually until it is completely integrated into the mud.

e) *Molding process*: The mixture is transferred to the yard or molding and drying zone, where the mixture is poured into molds, where it is pounded, the excess material is removed and the mold is demolded to obtain blocks with dimensions of approx. 38 cm long, 18 cm wide and 11 cm thick.

f) *Drying*: Minimum Mud brick must be allowed to dry for eight days before they can be moved to a storage area to continue drying for a further fifteen days.

A. *Configuration of mechanical tests*

1) *Initial Document Considerations*

Two samples were taken after the respective quartet of the material, those are called M1-2 and M2-2; M1-2 is a mixture without any asphalt content and M2-2 is a mixture with any asphalt. This activity is realized for obtained the moisture content in it, consist in dried and weighed to determine the moisture content of the material, see Table 6, for which the following formula was applied:

$$w = \frac{w_1 - w_2}{w_2} x100 \quad (1)$$

Where:

w = Humidity content in %.

w_1 = Sample's mass -wet (g).

w_2 = Sample's mass dry (g).

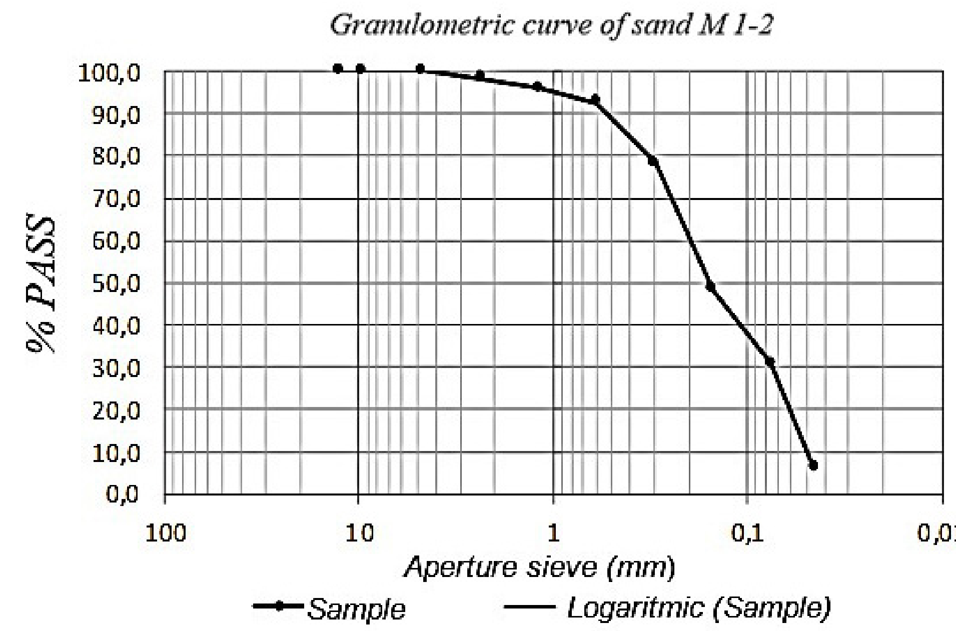
The granulometry test consists of passing through a series of sieves of progressively smaller dimensions a sample of the previously dried and heavy material to determine its distribution of particle size, the results are presented in Fig. 1.

The NTC-77 and NTC-78 guidelines were used to carry out this test, where it was identified that the minimum sample size should be 300 g and for determination of fineness modulus according to 9.2 "Calculates the fineness modulus, if required, as the sum of the percentages accumulated in the standard series of sieves from 150 µm onwards and divided by 100. The sieves of the standard series are: 150 µm (No. 100) , 300 µm (No. 50), 600 µm (No. 30), 1.18 mm (No. 16), 2.36 mm (No. 8), 4.75 mm (No. 4), 9.5 Mm, 19.0 mm, 37.5 mm and greater, increasing the rate from 2 to 1".

Table 6. Percentage wet in soil.

Samples	M1-2	M2-2
Weight sample wet	348.2 g	356.8 g
Weight sample dry	305.2 g	310.7 g
Wet percentage	14.09%	14.84%

Source: Authors.



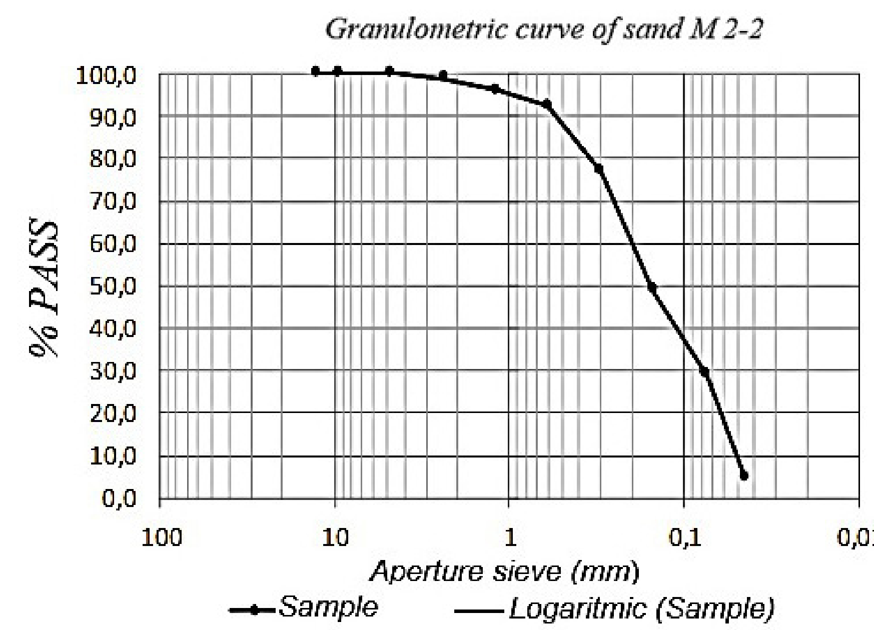


Fig. 1. Granulometrics tests results.
Source: Authors.

If looking Fig. 1, both mixtures (M1-2, M2-2) have a granulometric behavior in the same form, and granulometric curve slope indicated that they have different particle size, get smaller empty space, increasing density and mechanical properties for the Mud bricks.

B. *Density*

For the determination of the soil density that composes the Mud bricks, the test was carried out according to the Colombia Standard of INV-E-128 [34], which determines the specific gravity of the soils by means of the pycnometer. According to the standard the procedure was as follows:

a) By direct weighing we obtain:

Wb = Pycnometer mass + water + solids at test temperature (g)

Ws = Dry soil mass (g)

b) With this information the specific gravity was calculated with three decimals, using (2).

$$Gs_{20°C} = \frac{Ws \times K}{Ws + Wb - Wa} \quad (2)$$

Where:

K = Correction factor based on water density at 20°C, to express the specific gravity at 20°C. Obtained from the calibration of the pycnometer.

Wa = Mass of the pycnometer + water at the test temperature of specific gravity, in grams.

Ws = Dry soil mass (g).

Wb = Mass of the pycnometer + water + soil (g), at the test temperature.

And the soil density is obtained by multiplying the correction factor by the calculated specific gravity. The results are presented in Table 7.

TABLE 7. DETERMINATION OF SOIL DENSITY SOURCE FOR MATERIALS PARTICIPATING RECYCLED ASPHALT: OWN ELABORATION.

Results evaluations samples dry by oven	
Pycnometer+ Water + Soil (g)	719.11
Temperature test (°C)	26.2
Pycnometer+ Water TEMP-TEST	679.72
Recipient N°	N°7
Recipient weight (g)	103.77
Recipient + Dry Soil (g)	178.77
Dry Soil (g)	75.00
Correction factor (Gs20°C)	0.99835
Gs 20°C	2.102
Specific Gravity a 20°C	2.102
Density (g/cm³)	2.099

Source: Authors.

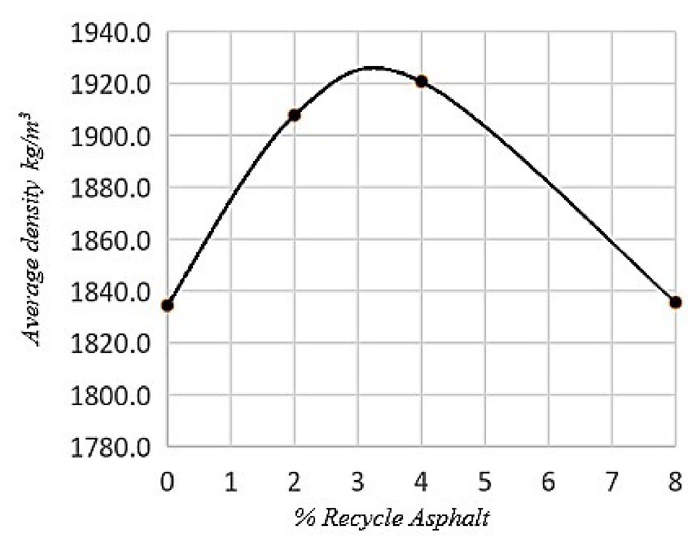


Fig. 2. Average densities according to recycled asphalt content.
Source: Authors.

C. *Compressive strength*

Because the samples were transferred to the university laboratory, some of the faces of the Mud brick were affected and therefore, so that the results of the tests were not altered by the irregularity of the Mud bricks, it was done It is necessary to place a confined sand quilt on a wooden device. Fig. 2, for the tests of resistance to simple compression was used as normative reference the NTC-4017 or ASTM C67-17 [35] that establishes calculating resistance to compression:

$$C = \frac{W}{A} \quad (3)$$

Where

C = Specimen strength to compression, in Pa × 10^4.

W = Maximum load (breaking), in N or that indicated by the test machine.

A = Average of the gross areas of the upper and lower surfaces of the specimen, in cm².

The results of the tests are presented in Table 8 and Fig. 3, Fig. 4, Fig. 5, Fig. 6, which relate the resistances to the pressure obtained in each sample according to their asphalt content are presented in Fig. 7.

Table 8. Ad features based on recycled asphalt content.

Characteristic		Mud brick without asphalt content	Mud brick with 2% asphalt content	Mud brick with 4% asphalt content	Mud brick with 8% asphalt content
Average Density (kg/m^3)		1834.4	1907.7	1920.8	1835.6
Strenght Compression	No. Samples	3	3	3	3
	Maximum Load (kN)	58.5	168.2	147.3	117.7
	Strength compression (kPa)	842.5	2466.8	2197.8	1698.1
	Standard desviation (kPa)	52.7	31.1	35.6	3.6
	Confidence level	90%	90%	90%	90%
	Error range	50.1	29.6	35.6	3.4
	Confidence interval (kPa)	842.5 ± 50.1	2466.7 ± 29.6	2197.8 ± 35.6	1698.1 ± 3.4
Flexion Strength	No. Samples	3	3	3	3
	Maximum Load (kN)	1.5	1.4	1.3	1.4
	Breaking module (kPa)	325.9	326.0	306.2	265.6
	Standard desviation (kPa)	11.1	3.3	4.0	32.0
	Confidence level	90%	90%	90%	90%
	Error range	10.6	3.1	3.8	30.4
	Confidence interval (kPa)	325.9 ± 10.6	326.0 ± 3.1	306.22 ± 3.8	265.63 ± 30.4

Source: Authors.

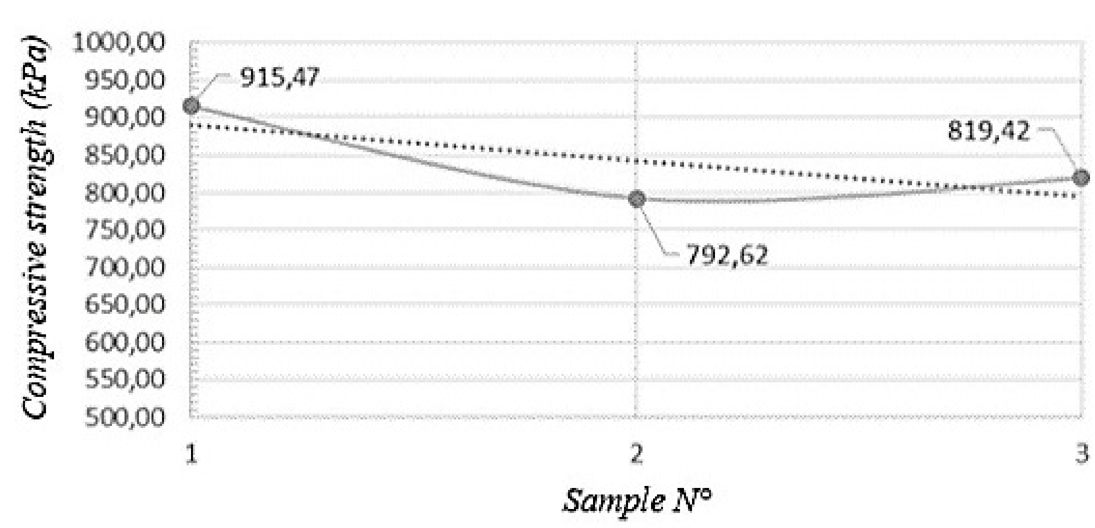


Fig. 3. Compressive strength in samples without asphalt content.
Source: Authors.

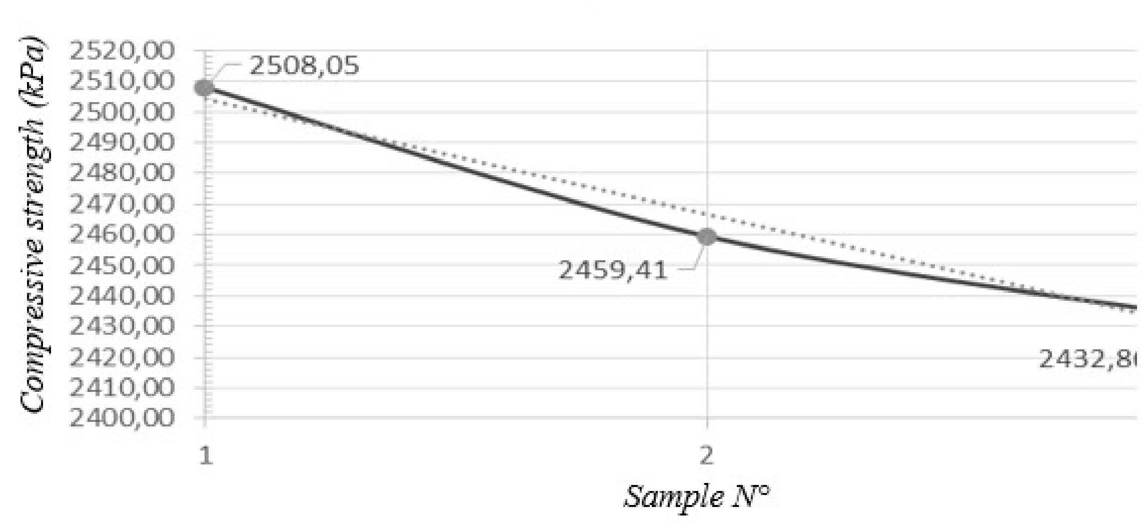


Fig. 4. Compressive strength in samples with 2% asphalt content.
Source: Authors.

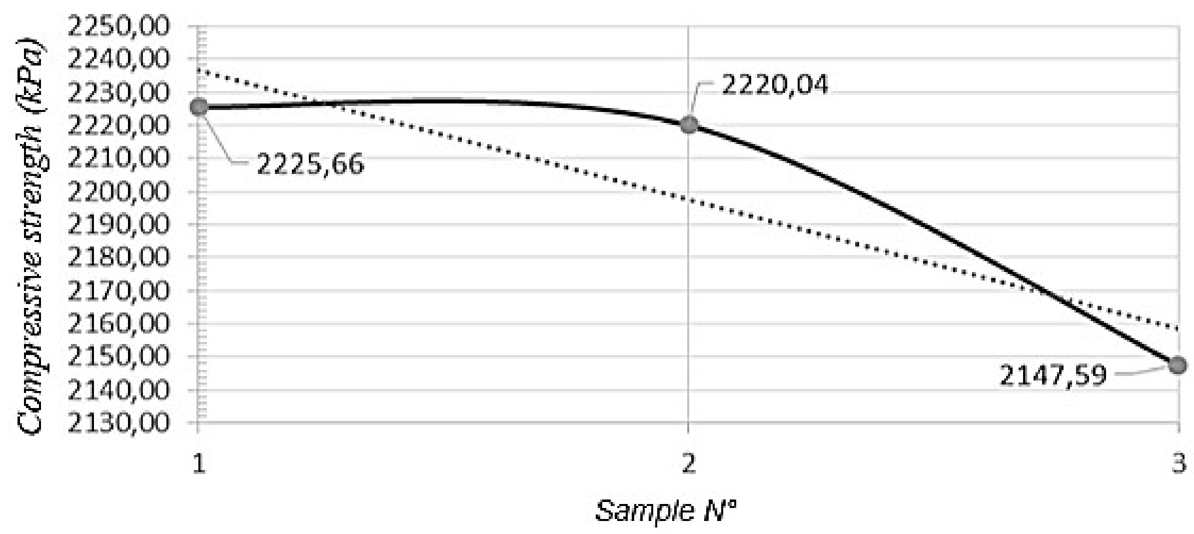


Fig. 5. Compressive strength in samples with 4% asphalt content.
Source: Authors.

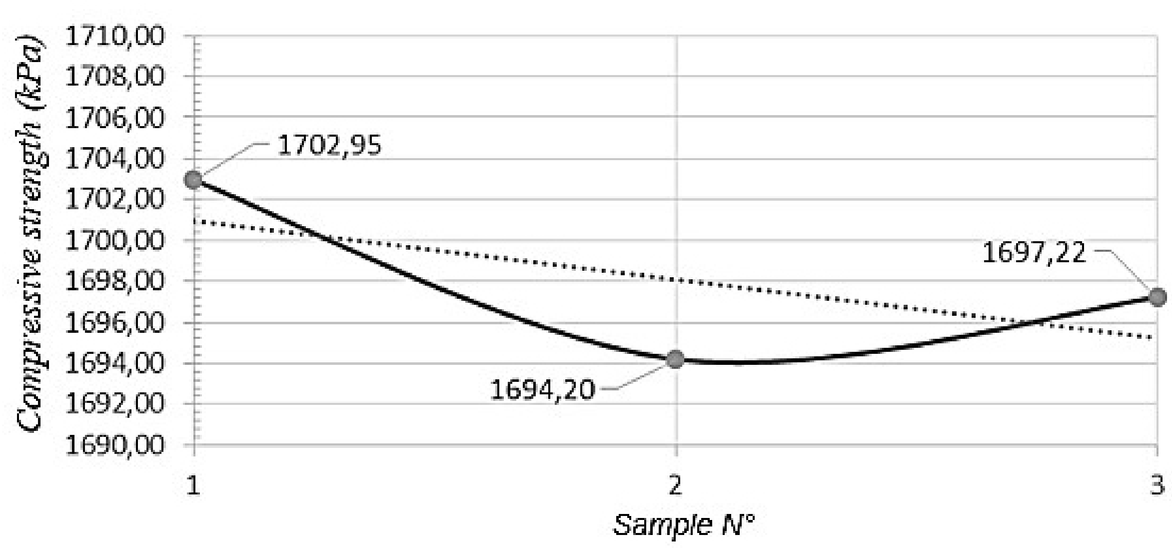


Fig. 6. Compressive strength in samples with 8% asphalt content.
Source: Authors.

Fig. 7. Registered photographic test of simple compression.
Source: Authors.

D. *Flexural Strength Test*

For the tests of resistance to the flexion was used the standard reference NTC-4017 or ASTM C67-17 [35] that establishes the following assembly see Fig. 8 for the determination of the module of rupture.

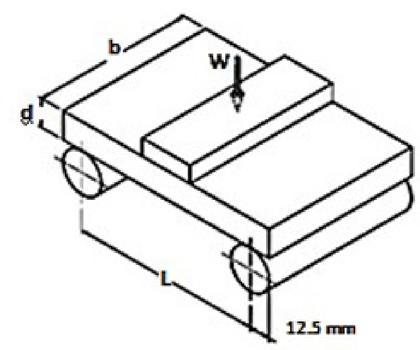


Fig. 8. Diagram of mounting module of rupture.
Source: Authors.

Where:

W = applied load in N.

L = Distance between the support brackets in mm.

b and *d* = Width and height respectively, in mm.

The rupture modulus of each of the samples was calculated as follows:

$$MR = \frac{W \, x \, L \, x \, Z}{4 \, x \, I} \quad (4)$$

Where:

MR = modulus of rupture in the middle of the light, in Pa × 104.

W = maximum load indicated by the test machine (breaking load) in N.

L = distance between the support brackets, in mm.

Z = distance from the neutral axis to the furthest side, in mm $Z = d/2$.

I = moment of inertia of the section, in cm^4 $I = (b \times d^2)/12$

The results of the tests are presented in Table 8 and the Fig. 10, Fig. 11, Fig. 12, Fig. 13 that relate the flexural strength obtained in each sample according to their asphalt content are presented in Fig. 9.

This figures were elaborated by average between 5 bricks by mixture and standard deviation 10 kPa.

Fig. 9. Photographic record of flexural strength test.
Source: Authors.

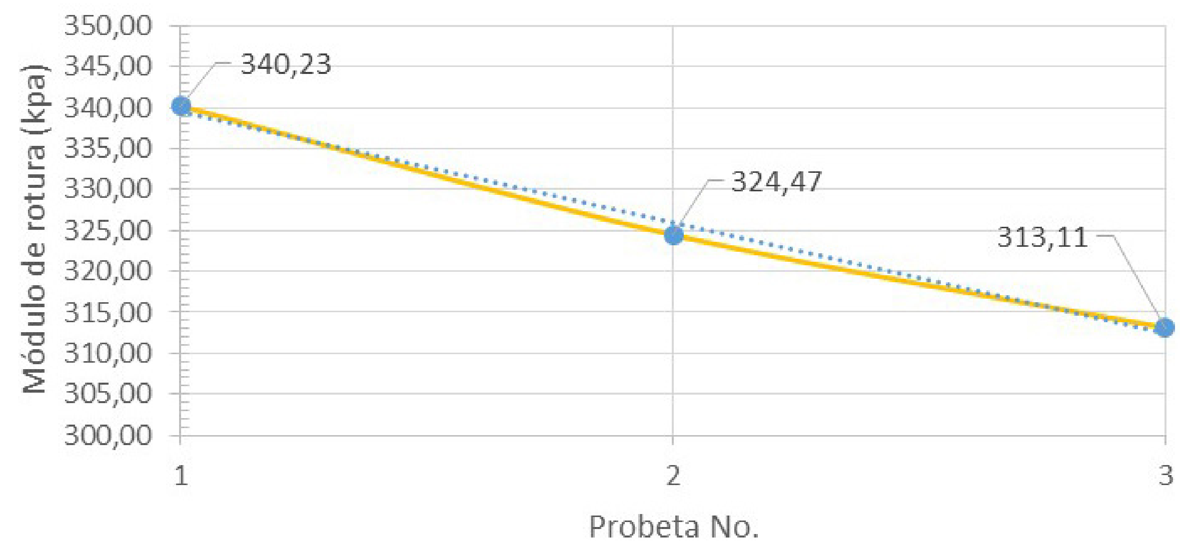


Fig. 10. Flexion strength in samples without asphalt content.
Source: Authors.

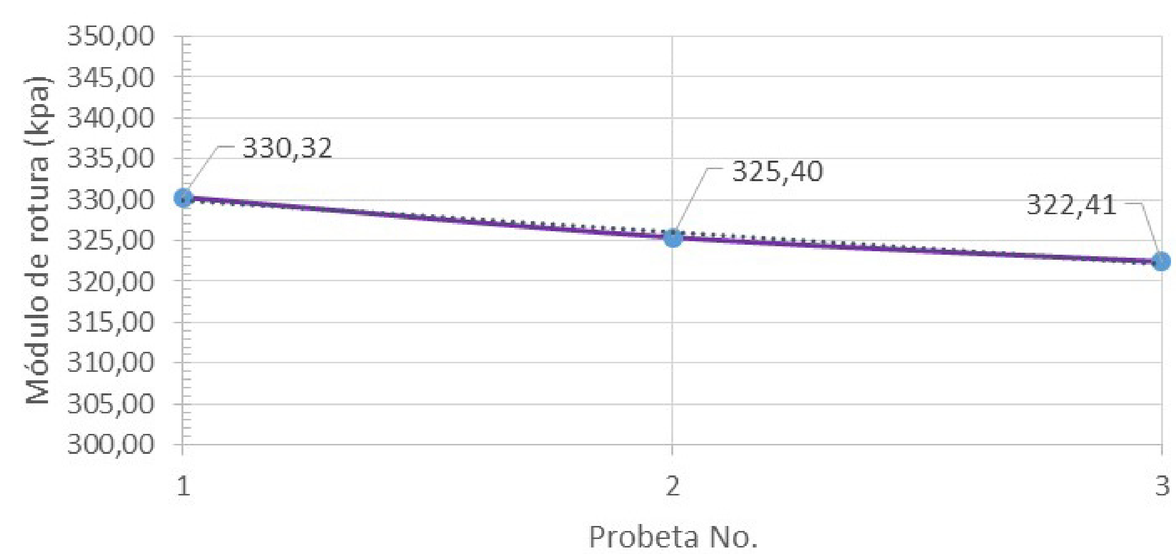


Fig. 11. Flexion strength in samples with 2% asphalt content.
Source: Authors.

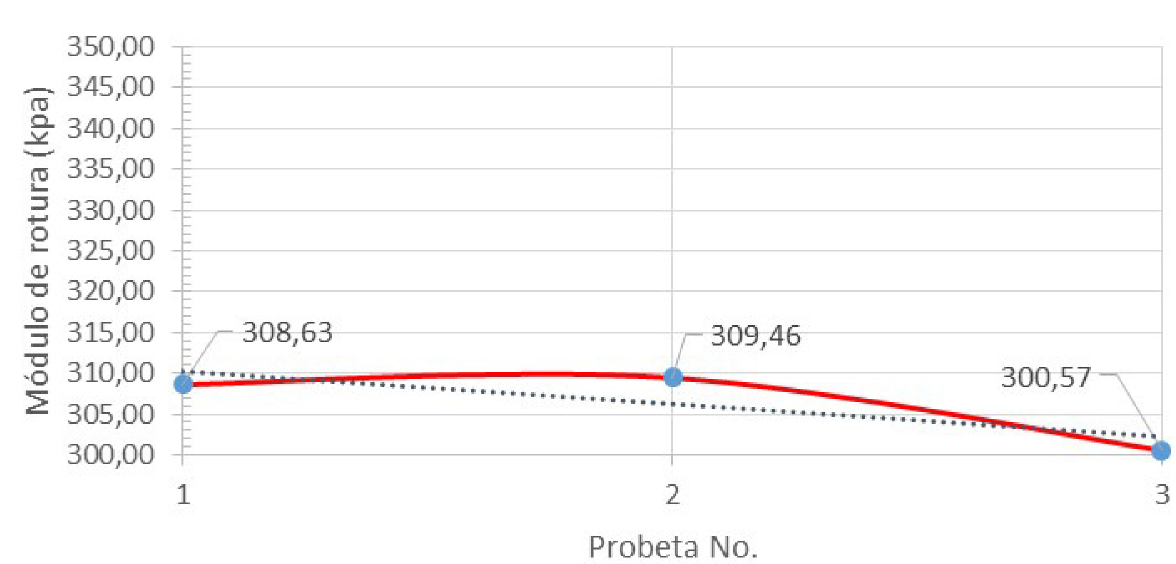


Fig. 12. Flexion strength in samples with 4% asphalt content.
Source: Authors.

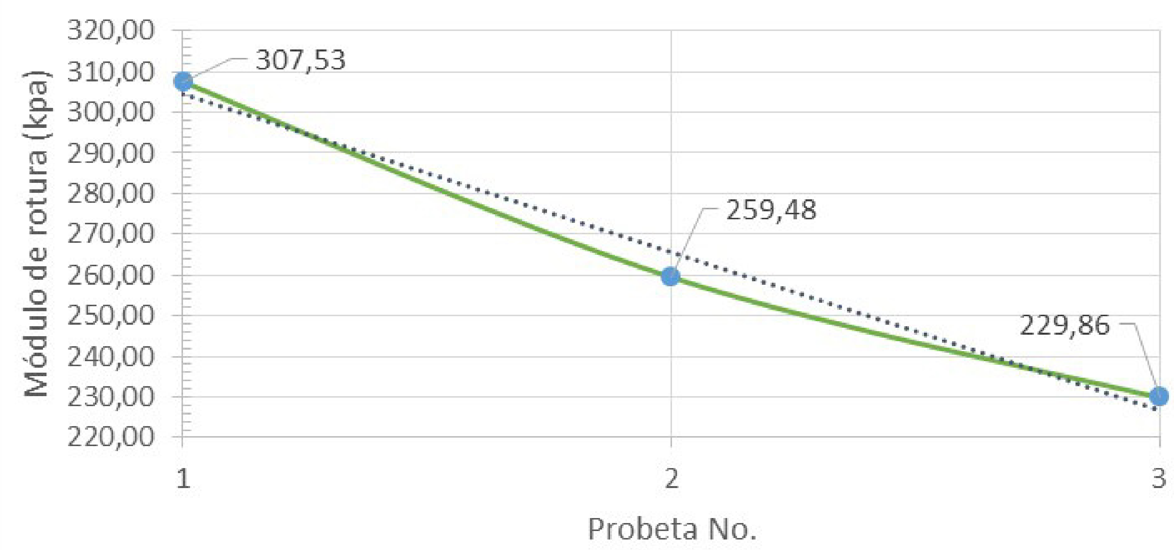


Fig. 13. Flexion strength in samples with 8% asphalt content.
Source: Authors.

IV. Results

To perform the analysis of the results obtained from the tests of resistance to compression and flexion, it was necessary to calculate the population standard deviation due to the dispersion observed in the results in both the compressive strength and the modulus of rupture.

The margin of error was determined with a confidence interval equal to 90%, this interval was established by human error factors, irregularity of the faces of the test specimens, homogenization of the mixture, variation of moisture content, etc., The observed values may present a margin of error.

According to the results obtained from the tests performed on both the soil that composes the mudbricks and the brick of dimension large 24 cm width 12 cm and high 12 cm; this were stabilized with asphalt at different dosages, the characteristics presented in Table 8 and in Fig. 14 and Fig. 15 can be identified Relate the asphalt content and its resistance behavior to compression and flexion.

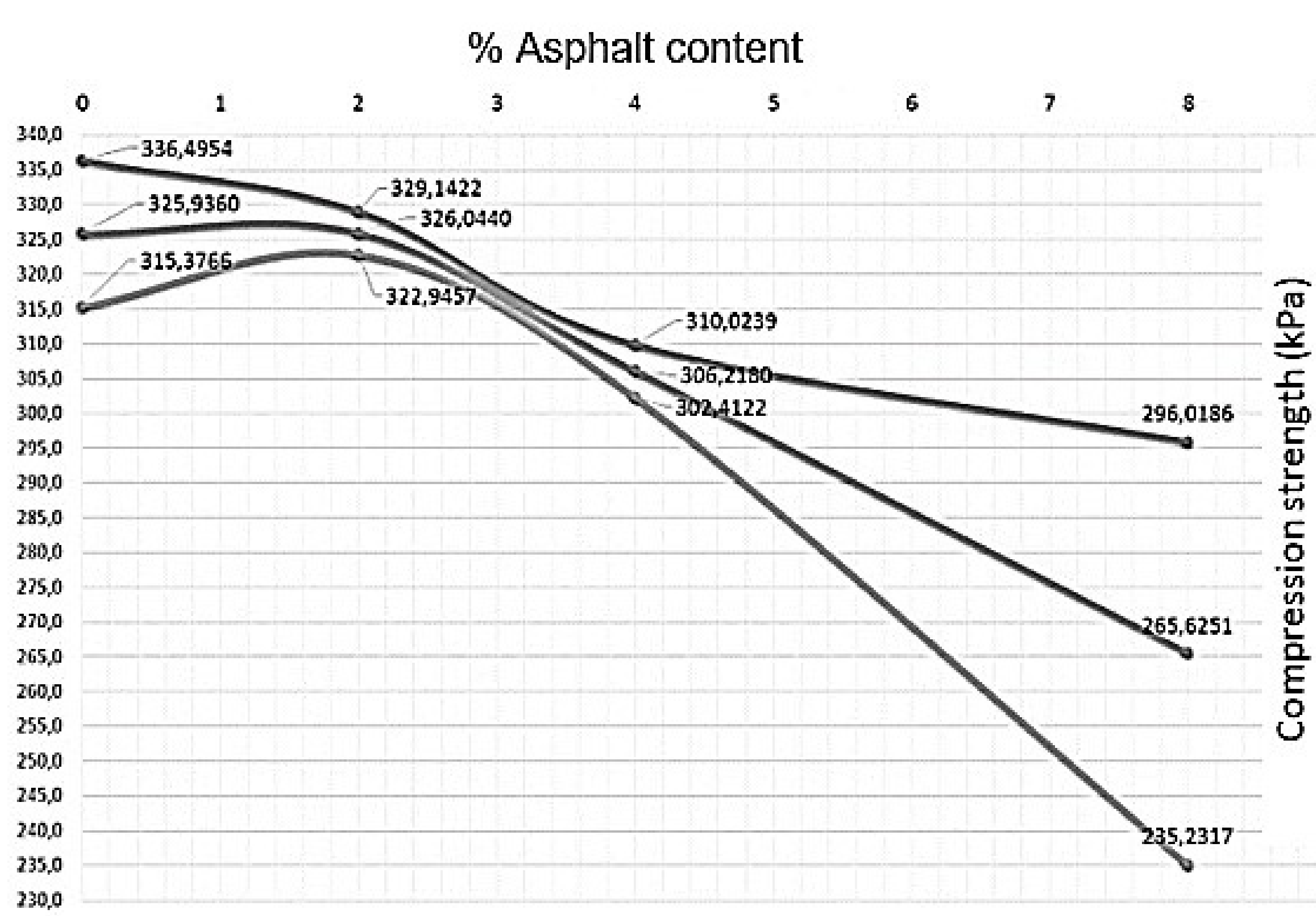


Fig. 14. Percentage of recycled asphalt vs compression strength
Source: Authors.

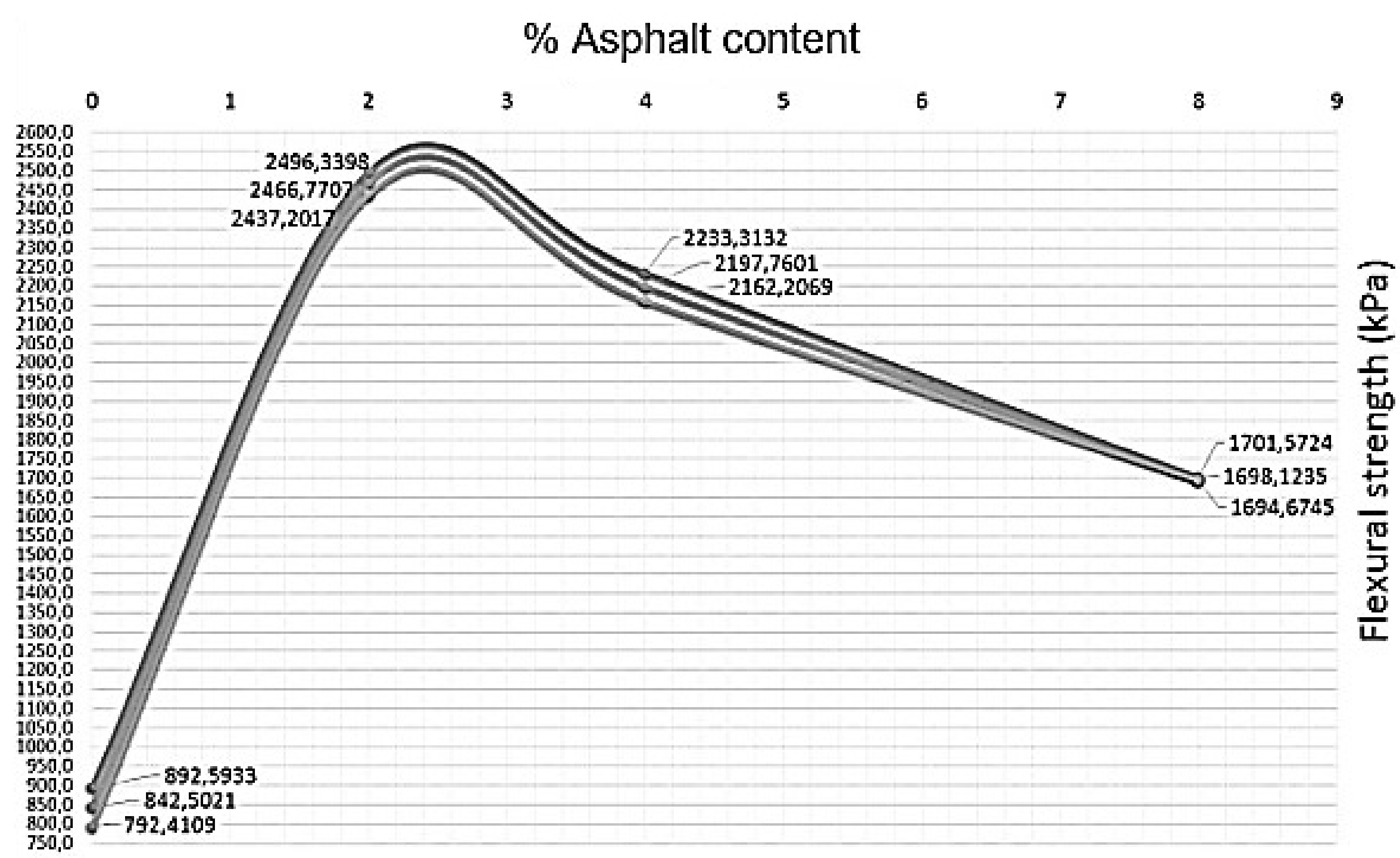


Fig. 15. Percentage of recycled asphalt vs flexural strength.
Source: Authors.

In the compression test the samples with the best resistance behavior were those with a content of 2% asphalt, the average maximum load was 168.16 kN and its compressive strength equal to 2466.7 kPa with a variation of ± 29.6 kPa, in contrast to the samples that presented less compressive resistance than those not stabilized with asphalt, its average maximum load was of 58.53 kN and its resistance to compression of 842,5 kPa with a Variation of ± 50.1 kPa.

This may be due to the fact that, according to what is discussed by some research [25], the effects of a good stabilizer are the increase in the compressive strength of the mudbrick by agglomerating its particles, reducing or eliminating water absorption by sealing the Holes and covering the clay particles and reduces the cracking of the mudbrick. Also, "if the soil presents a good compaction in the block realization, the resistance and density have a proportional relation" [20, p. 63].

The margin of error of the data obtained in the calculation of the compressive strength is significantly higher in the tests of the samples that were not stabilized with asphalt with a value of 50.09 against a margin of error of 3.44 in The samples with a content of 8% of asphalt, this could be due to the fact that in observing the dimensions of the samples present a greater dispersion in those without stabilizing in comparison with the other samples, this is caused because in the manufacture of the brick The process of removal of the excess of material and demolding is done manually and therefore cannot ensure homogeneity in the compactness of the mudbrick and its dimensions.

In the tests of flexural strength: there are not great differences in the value of the average maximum load, being higher in the samples without asphalt content (1.49 kN) and smaller in the samples with 4% content of asphalt (1.33 kN). The modulus of rupture in the samples with 2% asphalt content was the same as that of the non-stabilized samples (with an average value of 326 kPa), with the margin of error of the data being higher in the samples without asphalt content. It was also observed that the flexural strength in samples with 8% asphalt content decreased considerably with an average value of 265.62 kPa with a variation of ± 30.4 kPa despite its compressive strength being greater than In samples without asphalt content.

When comparing the standard deviation of the data obtained in the calculation of the modulus of rupture, the data with less dispersion were those of the samples with 2% of asphalt content and the ones of greater dispersion were presented in the samples with 8% of Asphalt content.

The behavior observed by the samples tested is due to the variations in the volumes of the bricks [36], this justifies the obtained value of the rupture modulus in the samples with 8%

asphalt content since their volumes in comparison with the other samples are larger, in addition, "its standard deviation will depend on the size of the specimen, so that increasing the volume of the sample (under load) increases the severity of the defects and consequently, the rupture modulus decreases".

A. *Evaluation of results*

In order to evaluate the obtained results, these were compared with the standard NTC-4205 that establishes the requirements that must be met by the bricks and a ceramic block used as masonry units and fixes the parameters with which the different types of units are determined.

According to this standard in 5.1.2 "the clay masonry units must meet the minimum compressive strength indicated in Table 9, when tested according to the procedure NTC-4017 or ASTM C67-17 [35]".

For explain Table 9, type PH are bricks with horizontal perforation, type PV are bricks with vertical perforation and M are bricks without perforation, solid bricks. The table explains technical requirements in Colombia.

Table 9. Standard phisical properties for units structural masonry according NTC-4205 "Propiedades físicas de las unidades de mampostería estructural".

Type	Minimum compressive strength* MPa (kgf/cm²)		Maximum water absorption %			
		Interior		Exterior		
	Average 5 U	Unity	Average 5 U	Unidad	Average 5 U	Unity
PH	5.0 (50)	3.5 (35)	13	16	13.5	14
PV	18.0 (180)	15.0 (150)	13	16	13.5	14
M	20.0 (200)	15.0 (150)	13	16	13.5	14

* In the case of vertical drilling bricks, the values exposed are minimum compressive strenght, in other case is average strenght.
Source: Authors.

Clay materials such as mudbrick are used as structural and non-structural masonry material and according to the results of the compression tests performed, the maximum resistance obtained by stabilizing the Mud brick was observed in the samples with 2% Recycled asphalt with a value equal to 2.46 MPa, however this value is much lower than the value of the minimum resistance of 15 MPa required in the norm NTC-4025 or ASTM C469/C469M-14 [37].

When comparing the obtained results of resistance to the compression and the flexion against the results presented by another study see Table 10, it is observed:

- That the value obtained experimentally in the tests of compressive strength in samples without asphalt content was 0.8 MPa, which is much inferior with respect to the value presented by [31].
- That the obtained value of flexural strength in non-stabilized samples was 0.32 MPa which is very close to the minimum value presented by [31].
- The obtained value of compressive strength in samples stabilized with 2% asphalt content was 2.43 MPa which is close to the value of 2.84 MPa presented by [31].
- That the obtained value of flexural strength in samples stabilized with 2% as-missing content (0.323 MPa) was slightly higher than the value presented by [31].

Table 10. Comparative between compressive strength and flexion research [31] and our results.

Mud brick characteristics	Results of the test		Mud brick Research [31]	Earth brick Research [31].
	Mud brick without asphalt content	Mud brick with 2% in asphalt		
Compresive Strength	0.842 MPa standard deviation 0.05 Mpa	2.46 MPa standard deviation 0.029MPa	2.84 MPa standard deviation 0.855 MPa	0.55 MPa standard deviation 0.184
Flexion strength	0.33 MPa standard deviation 0.01 Mpa	0.33 Mpa standard deviation 0.03 Mpa	0.49 Mpa standard deviation 0.188 Mpa	There are no results

Source: Authors [31].

V. Conclusions and Recommendations

During the sample preparation process, variations in the consistency of the material were observed at the time of mixing as the asphalt content increased.

According to the granulometry results, the soil used for the manufacture of the mudbrick is a material containing 70% sands and 30% fines. This characterization of the soil and taking into account other studies made and referenced, is within the limits suitable for the soil can be used for the manufacture of mudbricks, since the most favorable percentages are in the ranges of 55% to 80% Of sand, 10% to 28% of fines and 15% to 18% of clay.

In the density tests, a soil density of 2099 kg/m^3 was found and it was observed that the values of average densities increased as their asphalt content increased, which were equal to 1884.4 kg/m^3, 1907.7 kg/m^3 and 1920.8 kg/m^3, in samples with 0%, 2% and 4% of asphalt content respectively. A decrease in average density of 1835.6 kg/m3 was observed in the samples stabilized with 8% asphalt content.

When performing the compression tests of all the samples a lateral deformation was observed in the side faces of the material, indicating that it is a plastic material.

Increasing the asphalt content in the mudbrick shows a reduction in its resistance to both bending and compression, because the density of the material and the adhesion between the particles decreases.

At the mean values of compressive and flexural strength, the respective standard deviation was calculated with a 90% confidence level because the results showed great dispersion since there are factors such as the irregularity of the faces which may generate errors in the tests.

The best mechanical comportment, it was obtained in the mudbricks mixture with 2% of recycle asphalt, both in its resistance to compression and to the flexion. If it compared with another results, mudbricks and rammed earth walls, comportment of mudbricks mixture with 2% of recycle asphalt is twice better than this materials, therefore use recycle asphalt improve mechanical behavior for mudbricks.

The results of resistance to compression are lower than the limits of resistance presented in the NTC-4025 or ASTM C469/C469M-14 [37], however compared to the mudbrick without asphalt its mechanical behavior is better.

It is recommended to carry out studies related to the behavior of the stabilized mudbrick with asphalt in walls to identify its structural behavior and by conducting tests such as the vibrating table, to identify its behavior in the presence of seismic movements.

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