Characterization for compression tests on pet bottles of 600 millilitres, 1.5 and 2.0 liters; filled with sand and particle size of 1.19 mm

Caracterización para ensayos de compresión a botellas de pet de 600 mililitros, 1.5 y 2.0 litros; con llenado de arena y tamaño de partículas de 1.19 milímetros

Caracterização para testes de compressão em garrafas pet de 600 mililitros, 1,5 e 2,0 litros; preenchido com areia e partícula de 1,19 mm

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Abstract

Introduction: This article is the product of a research project carried out between 2020 and 2021, with the academic support of Francisco José de Caldas District University, Bogotá Technological Headquarters - Colombia. (CHARACTERIZATION FOR COMPRESSION TESTS ON PET BOTTLES OF 600 MILLILITRES, 1.5 AND 2.0 LITERS; FILLED WITH SAND AND PARTICLE SIZE OF 1.19 MM).

Problem: Propose a construction material for the housing sector, especially aimed at the department of La Guajira, which currently faces a high housing deficit in Colombia.

Objective: The objective of this research project is the characterization of 600 mL, 1.5 L and 2.0 L PET bottles, filled with sand whose particle size is 1.19 mm.

Methodology: 12 test tubes were designed for each bottle size. The respective weighing process was carried out before and after filling; The tests consisted on applying compression loads, until reaching structural breakdown.

Results: The different testing scenarios showed similar resistance parameters. The 600 mL size presented a higher breakdown load than the 1.5 and 2.0 L sizes. The breakdown loads remained within the range of 138 ≤ breaking load (KN) ≤ 240.

Conclusion: The compressive strengths of the studied materials do not show significant differences. Resistance for bricks = 4.9 MPa and PET (600 ml) = 5.2 MPa

Originality: The bibliographic review covers a variety of reusable products used for the manufacture of materials in housing construction. The originality lies in the behavior of PET bottles filled with sand for a particle size of 1.19mm, subjected to compression tests in the universal testing machine.

Limitations: Only particle sizes of 1.19mm were used.

Keywords: Polyethylene terephthalate – PET (Polyethylene terephthalate), test tubes, resistance, breakage, particle.

Resumen

Introducción: el presente artículo es producto de la investigación realizada en el periodo 2020 a 2021, con el apoyo académico de la Universidad Distrital Francisco José de Caldas, Sede Tecnológica; Bogotá – Colombia. (CARACTERIZACIÓN PARA ENSAYOS DE COMPRESIÓN A BOTELLAS DE PET DE 600 MILILITROS, 1.5 Y 2.0 LITROS; CON LLENADO DE ARENA Y TAMAÑO DE PARTÍCULAS DE 1.19 MILÍMETROS).

Problema: plantear un material de construcción al sector vivienda, especialmente al departamento de la Guajira, el cual enfrenta un déficit de vivienda alto en Colombia.

Objetivo: el objetivo del presente proyecto de investigación es la caracterización de las botellas de PET de 600 ml, 1.5 litros y 2.0 litros, con llenado de arena y tamaño de partícula de 1.19 mm.

Metodología: Se diseñaron 12 probetas por tamaño de botella, se realizaron los pesajes respectivos antes y después del llenado; los ensayos realizados fueron a compresión sometiéndolos a la ruptura.

Resultados: Las diferentes probetas presentaron resistencias similares, la probeta de 600 ml presentó una carga a la ruptura superior a las probetas de 1.5 y 2.0 litros. Los rangos establecidos para los ensayos elaborados están en 138 ≤ carga de ruptura (KN) ≤ 240.

Conclusión: las resistencias a compresión de los dos materiales comparados no marcan diferencias significativas. Resistencia ladrillo = 4.9 MPa y PET (600 ml) = 5.2 MPa

Originalidad: la revisión bibliográfica presenta gran variedad de productos reutilizables utilizados para la fabricación de materiales en la construcción de vivienda, la originalidad es el comportamiento de las botellas de PET llenas de arena para tamaño de partícula 1.19mm, sometidas a pruebas de compresión en la maquina universal de ensayos.

Limitaciones: Solo se utilizaron tamaños de partícula de 1.19mm.

Palabras clave: Tereftalato de polietileno – PET (Polyethylene terephthalate), probetas (test tubes), resistencia (resistance), rotura (break), partícula (particle).

Resumo

Introdução: Este artigo é produto de pesquisa realizada no período de 2020 a 2021, com o apoio acadêmico da Universidade Distrital Francisco José de Caldas, Sede Tecnológica de Bogotá – Colômbia. (CARACTERIZAÇÃO PARA TESTES DE COMPRESSÃO EM GARRAFAS PET DE 600 MILILITROS, 1,5 E 2,0 LITROS; PREENCHIDO COM AREIA E PARTÍCULA DE 1,19 MM).

Problema: propor um material de construção para o setor habitacional, especialmente para o departamento de La Guajira, que enfrenta um alto déficit habitacional na Colômbia.

Objetivo: o objetivo deste projeto de pesquisa é a caracterização de garrafas PET de 600 ml, 1,5 litros e 2,0 litros, preenchidas com areia e com granulometria de 1,19 mm.

Metodologia: foram desenhados 12 tubos de ensaio por tamanho de garrafa, ases respectivas pesagens foram realizadas antes e após o enchimento; Os ensaios realizados foram sob compressão, submetendo-os à ruptura.

Resultados: os diferentes corpos de prova apresentaram resistências semelhantes, o corpo de prova de 600 ml apresentou maior carga de ruptura que os corpos de prova de 1,5 e 2,0 litros. As faixas estabelecidas para os testes elaborados são 138 ≤ carga de ruptura (KN) ≤ 240.

Conclusão: as resistências à compressão dos dois materiais comparados não apresentam diferenças significativas. Resistência do tijolo = 4,9 MPa e PET (600 ml) = 5,2 MPa

Originalidade: a revisão bibliográfica apresenta uma grande variedade de produtos reutilizáveis utilizados para fabricação de materiais na construção de habitações, a originalidade é o comportamento das garrafas PET preenchidas com areia para uma granulometria de 1,19mm, submetidas a ensaios de compressão nos ensaios universais máquina

Limitações: Trabalhamos apenas com tamanhos de partículas de 1,19mm

Palavras-chave: Polietileno tereftalato – PET (Polietileno tereftalato), tubos de ensaio, resistência, quebra, partícula.

1. Introduction

The need to build a home comes from mankind itself, initially to seek shelter from environmental conditions, animals or other humans; eventually, men developed new ideas and tools for construction. The evolution of different techniques and progress within the industry has facilitated massive constructions, creation of mechanical systems and environmental adequation in order to meet user needs. Having a safe place to live is one of the cornerstones of human dignity, physical and mental health and quality of life. Housing is a human right and an extension of people in current society. There is a close connection between poverty and being homeless, which marks a social impact, evidenced by a habitational deficit as a consequence of poverty and unemployment conditions; the struggle to have a home is also a struggle against poverty, since it affects social policies and habitability, directly linked to poverty and welfare within households.

Housing took a key role in the development of people [1], along with the right of proper quality life for families, including food, clothes and housing, and a continuous improvement of existence itself [2]; historically, homes have been built from a sense of pride and a personal commodity. Hence, they eventually became a sign of distinction and gave way to palaces, castles and emblematic constructions. After the Industrial Revolution, homes went from marvelous and culture-related buildings to become shelters in the peripheral areas of many cities. Only some decades ago did housing gained relevance in human growth, keeping in mind that homes are not just shelters but they must also be comfortable and relaxing. It is estimated that there are close to 100 million homeless people and 1 billion people live in inadequate housing conditions worldwide [3].

In Colombia, all citizens have the right to a decent home. The government determines the necessary conditions to ensure this right and fosters housing plans of social welfare, proper financing systems and associative methods of execution for said plans [4]. However, the execution of these programs depends on the resources available. In Colombia, close to 36.59% of the population does not have a roof to live or lives under precarious conditions. The habitational deficit is 24.84% in main cities and a staggering 80.99% in the rural areas. The access to proper housing conditions translates into a reduction of multidimensional poverty metrics, hence its importance. Nonetheless, granting a home, is an important challenge given implications such as available land for construction, the interconnection and coverage of public services, the development of infrastructure and the accessibility to resources for all inhabitants [5]. The national Census of Population and Housing from 2018 states that there are 14.060.045 households (excluding homes that live in ethnic or indigenous environments) with 9.8%, i.e. 1.378.829 homes live in deficient quantitative conditions and 26.78%, i.e. 3.765.616 homes live in deficient qualitative conditions [6]. The Urbanization and Housing Policy study from the Inter-American Development Bank (IDB) and UN Economic Commission for Latin America and the Caribbean (UNECLAC) stated in 2014 that the housing deficit in Colombia between 2008 and 2012 was 37%. A decade later, the country maintains about the same percentage of population with habitational issues, seeing a slight reduction of 0.41%. About 18.2 million Colombians live in a state of habitational deficit (with lacking conditions in terms of residential quality), which represents 36.59% of the population [7].

In Colombia, the construction sector has seen a good performance and growth dynamic. The number of square meters to be executed increased by 6% in September 2016. In 2015, this sector contributed to an increase in the GNP. The construction sector remains one of the most important ones within the productive structure given its employment generation capacity and its impact in the cement, metallurgy and transportation industries. For some regions such as Guajira, this activity has become less frequent since 2014 and the trend is still true to this day. Between the years 2013 and 2016, the areas used for construction each year were 102.023, 83.492, 65.882 and 43.899 m^2, mostly for housing purposes. From 2014 to 2015, there was a negative variation of 21.1%, so the construction sector did not contribute to the growth of the regional GNP [8].

The National Development Plan launched during the second term of president Juan Manuel Santos (2014-2018), was based on three pillars (peace, equality and education), and sought to achieve a country with equitable conditions and zero extreme poverty [9]. The project proposed the characterization of PET bottles of 600 mL, 1.5L and 2L and use them as an alternative in housing construction in the Guajira region, seeking to replace bricks. These eco-friendly bricks have been used to build highly resistant and low-weight buildings, while ensuring adequate thermal conditions and access to low-income communities.

1.1 Literary review and research

Since the era of the first civilizations, the residues left from human activity have increased over time and led to many inconveniences such as diseases, contamination and reduction of quality life for some communities.

Society has tried to create numerous solutions to counter these issues; environmental awareness has risen in current generations through the improvement of processes by achieving the expected efficiency and lowering the emission of harmful agents. One of these solutions is recycling which consists on collecting common materials to turn them into raw materials. PET (polyethylene terephthalate) bottles are an example of a material that can be recycled to avoid its impact in the environment.

The Declaration of the Millennium states that no efforts must be stopped to release mankind, and especially our children and grandchildren, from the threat of a planet that is damaged beyond repair by human activity and whose resources are not enough to supply for basic needs [10]. The World Economic Forum delivers annual reports on worldwide risks and these have shown rapid growth; In 2013, it is evidenced that there is a clear disparity in terms of rent, which has a strong negative economic impact. Climate change is the most likely environmental matter, being accelerated over time and having significant impact on the economy [11].

Construction projects in Colombia need to consider their intrinsic impact on the environment. The responsibility of the construction sector regarding climate change is relevant, since it has a direct effect on the development of society given the production of waste, transformation of the physical environment, contamination and considerable use of energy. Hence, this productive sector cannot be indifferent to current environment issues [12].

The first researcher to study the use of recycled materials in construction was Michael Reynolds in the 70s. In 2005, the Physical Sciences teacher Tomislav Radovanovic replaced bricks with 14.000 plastic bottles filled with land to build a 60 m^2 house in the province of Kragujevac (Belgrade). The construction of houses with this type of materials results in an innovative construction system, that transforms solid waste into useful materials for housing. At the same time, it also offers advantages such as stability and thermal isolation, while improving the economy. However, this system is not regulated nor characterized as stated by James [13].

This system has proven to have a low ecological and environmental impact (due to the reuses of bottle and soil), low cost-since unskilled labor and materials considered waste are used providing flexible and economic housing solutions, according to the needs of the poorest communities [14].

The structural eco-block for rural housing involves the use of PET bottles. This material has led to many advantages to the construction sector, including a reduction of the impact caused by plastic bottles. Studies have shown that blocks made from PET can be used in non-structural homes while saving money in comparison to conventional bricks [15].\

The support from institutions to the communities has not been sufficient. Up to this day projects have been developed through trial and error methods, without proper regulation and noncompliance to the earthquake-resistant norm NSR-10 [13].

Many variables are involved in the resulting destination of plastic residues. Nowadays, companies within the industry have no plans to cutback on plastic-induced contamination. Many fast-consumption companies do not implement strategies that contribute to the reduction of single-use plastics and have never analyzed the entire lifecycle of their products. Furthermore, a circular model has not been contemplated in the management of solid waste within these production cycles. Therefore, the responsibility of disposing of this waste falls in hands of the consumers and communities who suffer the impact of its accumulation over time. "Still, the producers of plastic that contaminate the planet forecast that the production of plastic will quadruple by

2050 (from 311 Megatons in 2014 to 1124 Megatons in 2050). Close to 8.3 billion tons of plastic have been produced since 1950, yet only 9% has been recycled. The remaining 91% is divided between 12% that has been burned and 79% that has been sent to landfills or natural ecosystems. It is estimated that 12.7 million tons of plastic waste entered the oceans in 2010, i.e. the equivalent of an entire truck throwing plastic every minute. Low-income communities living close to the plastic production sites face harsher health-related consequences given the exposition to toxins and garbage. They are the main target affected by the effects of improper disposal and incineration of plastic [16]."

Continuing with the topic below are mentioned other projects where recycled material has been used in building elements:

- It is proposed to use recycled PET material for the construction of walls, for this, innovation proposals were developed for the format of the same, based on the vision that anyone can build it. In addition, laboratory tests were carried out to technically validate each approach. This idea could reduce the amount of PET that is currently discarded and contribute to improving the structural security of self-building homes in the coming years, with this could benefit families living in poverty and / or marginalization. [17]
- A simulation is developed for the use of recycled materials for the construction of low-cost housing, the previous designs that were made for the house are feasible since they support the static loads that are generated, taking into account the results obtained through SAP. The materials that will be used for the construction are of great resistance and easy access, which allows to reduce costs and reduce environmental impacts. The house does not have an analysis of dynamic loads, but we can conclude that it is a light and flexible house that can resist telluric movements. The social impact generated by the project is positive, as it allows to improve the quality of life of those people who do not have enough resources for housing, additional the project manages to satisfy the basic needs of a population, because this is designed to provide this opportunity to several families in need. [18]
- We want to implement the ecological house as a way to avoid excess pollution, reduce water and energy consumption, trying to reuse water in addition to making better use or giving effective use to rainwater as well as making the most of the sun's energy through solar panels. As well as we must become aware and think about the future about what we can achieve with a good management of natural resources. People have performed deeds

and acts in order to satisfy their desires and needs; man, always had that capacity to be able to transform reality, taking into account the materials he possesses at the moment in which he finds himself. It should be noted that not all the advances made by man were made on a straight path, for this he had many and difficult obstacles, however, he always appealed to his ingenuity and creativity, taking as an element the existing science and technology. [19]

- A project studies the behavior of the different elements that make up these construction systems; types of bottles and arrangements in the space, fillings of the same, and joints between them within the construction system. In order to create a solid criterion, a construction procedure, that provides information about which bottles to use and how to use them either how to place them in space, how to fill them or how to tie them together, to meet certain needs that we seek for a wall, focusing on the structural ones, so that this criterion is used to build from now on, and to promote a very economical form of construction that can be very useful especially in the contexts of poverty in third world countries. [20]
- An article evaluates the mechanical properties of the solid ceramic bricks manufactured by hand in the municipality of Ocaña, applying in the first instance physical characterization tests of the clay used as raw material, and then perform non-destructive and destructive quality control tests of the masonry bricks that were selected among the different chircales or productive units of the sector, using for this purpose, the Colombian technical standard NTC-4017. [21]
- An investigation analyzes the construction technique called construction with recycled PET bottles, used in recent years by architects and ecologists, including in our country, as a new method of creating sustainable architecture, avoiding environmental pollution and promoting at the same time the possibility of self-construction with this type of materials. [22]
- Architects without borders develop a manual for the construction of houses from plastic bottles, the purpose of this manual is to provide communities with a simple guide to the application of the construction systems of different building elements. [23]
- In a work, an investigation was carried out that allows us to verify that pet in a second use can be used as an alternative construction system. The construction was carried out with two prototypes made with pet bottles, filling them, the first, with sawdust and the other with tepetate, covering

both with concrete and finally with white paint on the outside. Dattalogers were placed at 30, 60 and 90 cm inside to obtain temperature and humidity daily during winter and spring for periods of 15 days, likewise, in spring, applying on both white paint on the outside, in a dry semi-cold climate. [24]

The central subject of this article is the characterization of recycled materials, in this case, PET bottles that can be used in construction. The purpose is to determine which criteria enable the comparison of this construction alternative to a conventional system. Hence, various experiments were carried out involving the compression of sand-filled bottles to test their resistance.

2. PROCEDURE AND METHODOLOGY

2.1 MATERIALS AND EQUIPMENT

2.1.1 Selection of plastic bottles and sand.

PET Coca-Cola bottles were collected and washed, with sizes of 600 mL, 1.5 L and 2 L. These bottles were filled with boulder sand with the particle sizes (range): 0.0625 mm to 2 mm (particle size for this type of sand). For the studied case, a particle size of 1.19 mm was chosen (mesh 16). The compression process is carried out through 10 hits per layer and the filling process is divided in three layers: layer 1, base of the central cylinder, layer 2, from the cylinder to the shoulders and layer 3, from the shoulders to the neck. Figure 1 represents the filling layers per bottle.

Figure 1. Filling layers per bottle.
Source: Author.

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2.1.2 Preparation of the selected bottles

The bottles selected to be filled are shown in Table 1.

Table 1. Bottle dimensions.

	Cylinder length (mm)				Cylinder diameter (mm)			
Bottle size	**Neck**	**Shoulders**	**Center**	**Base**	**Neck**	**Shoulders**	**Center**	**Base**
600 mL	40	30	125	30	95	200	225	225
1,5 L	60	40	170	40	100	280	300	300
2 L	80	35	190	55	100	340	365	365

Source: Author.

Table 2 shows the weights for all types of bottles and tests:

Table 2. Weight of the bottles.

Test No. 1

Bottle	Weight without sand	Weight with sand
600 ml	23.86 gr	1084.86 gr
1,5 L	43.79 gr	gr
2 L	r	3569.00 gr

Source: Author

Table 3. Weight of the bottles.

Test No. 2

Bottle	Weight without sand	Weight with sand
600 ml	23.78 gr	1099.20 gr
1,5 L	43.80 gr	2785.23 gr
2 L	gr	3650.00 gr

Source: Author

Table 4. Weight of the bottles.

Test No. 3

Bottle	Weight without sand	Weight with sand
600 ml	23.98 gr	1052.87 gr
1,5 L	43.95 gr	2523 gr
2 L	gr	3578 gr

Source: Author

2.1.3 Experiments of resistance to compression

The bottles were subjected to compression experiments with a universal testing machine (REF. UH 50-A Shimatzu). Each bottle was subjected to breaking point. Figure 2 represents the disposition of the bottle within the machine.

A B C

Figure 2. Bottle disposition in the machine.
Source: Authors.

The bottles were placed over the flat surface of the machine. The upper circular section applies a load over the cylindrical bottle (Figure 2B). Figure 3 shows the bottles subjected to maximum loads with structural breakdown as a result.

Figure 3. Maximum breakdown loads.
Source: Authors

2.2. METHODOLOGY

Coca-Cola PET bottles were used with sizes of 600 mL, 1.5 L and 2 L. The bottles were washed, measured and weighed before being filled with sand. The resistance to compression tests involved 12 tests tubes per experiment. The bottles were subjected to horizontal compression which is perpendicular to the discs of the universal test machine (Figure 4).

Figure 4. Disposition of the test tubes.
Source: Authors.

2.3 RESULTS

These are the results for the compression tests:

Table 5. Results for maximum resistance to compression for 600 mL, 1.5 L and 2 L bottles.

Test No. 1

	Test tube	Maximum load to reach breakdown (KN)	Maximum Resistance (MPa)
600 ml bottle Area: 149.34 cm2	1	242,81	16258,87
	2	240,23	16086,11
	3	235,14	15745,28
	4	220,38	14756,93
Average load		**234,64**	**15711,80**

	Test tube	Maximum load to reach breakdown (KN)	Maximum Resistance (MPa)
1.5 L bottle Area: 280.24 cm2	1	118,02	4211,39
	2	120,03	4283,11
	3	168,33	6006,64
	4	150,35	5365,04
Average load		**139,182**	**4966,55**

	Test tube	Maximum load to reach breakdown (KN)	Maximum Resistance (MPa)
2L bottle Area: 366.98 cm2	1	139,11	3790,67
	2	152,35	4151,45
	3	186,45	5080,66
	4	129,77	3536,16
Average load		151,92	4139,74

Test No. 2

	Test tube	Maximum load to reach breakdown (KN)	Maximum Resistance (MPa)
600 ml bottle Area: 149.34 cm2	1	254,36	17032,28
	2	258,56	17313,51
	3	245,65	16449,04
	4	216,35	14487,08
Average load		**234,64**	**16320,48**

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	Test tube	Maximum load to reach breakdown (KN)	Maximum Resistance (MPa)
1.5 L bottle Area: 280.24 cm2	1	120,35	4294,53
	2	125,63	4482,94
	3	180,65	6446,26
	4	132,54	4729,52
Average load		**139,182**	**4988,31**

	Test tube	Maximum load to reach breakdown (KN)	Maximum Resistance (MPa)
2L bottle Area: 366.98 cm2	1	145,23	3957,44
	2	163,25	4448,47
	3	175,89	4792,90
	4	132,56	3612,19
Average load		**151,92**	**4202,75**

Test No. 3

	Test tube	Maximum load to reach breakdown (KN)	Maximum Resistance (MPa)
600 ml bottle Area: 149.34 cm2	1	258,36	17300,12
	2	235,26	15753,31
	3	256,14	17151,47
	4	225,68	15111,83
Average load		234,64	16329,18

	Test tube	Maximum load to reach breakdown (KN)	Maximum Resistance (MPa)
1.5 L bottle Area: 280.24 cm2	1	132,52	4728,80
	2	115,45	4119,68
	3	174,56	6228,95
	4	127,65	4555,02
Average load		**139,182**	**4908,11**

	Test tube	Maximum load to reach breakdown (KN)	Maximum Resistance (MPa)
2L bottle Area: 366.98 cm2	1	128,56	3503,19
	2	142,56	3884,68
	3	142,65	3887,13
	4	158,32	4314,13
Average load		**151,92**	**3897,28**

Source: Authors.

The results obtained are: For 600 mL, the maximum load is 240.74 KN.

Table 6. Maximum resistance to compression for 600 mL bottles.

	Maximum load to reach breakdown (KN)
Bottles 600 ml	234,64
	243,73
	243,86
Average load	**240,743**

Source: Authors

For 1.5 L bottles, the maximum resistance to compression is 138,84 KN.

Table 7. Maximum resistance to compression for 1.5 L bottles.

	Maximum load to reach breakdown (KN)
1.5 L bottles	139,182
	139,792
	137,545
Average load	138,84

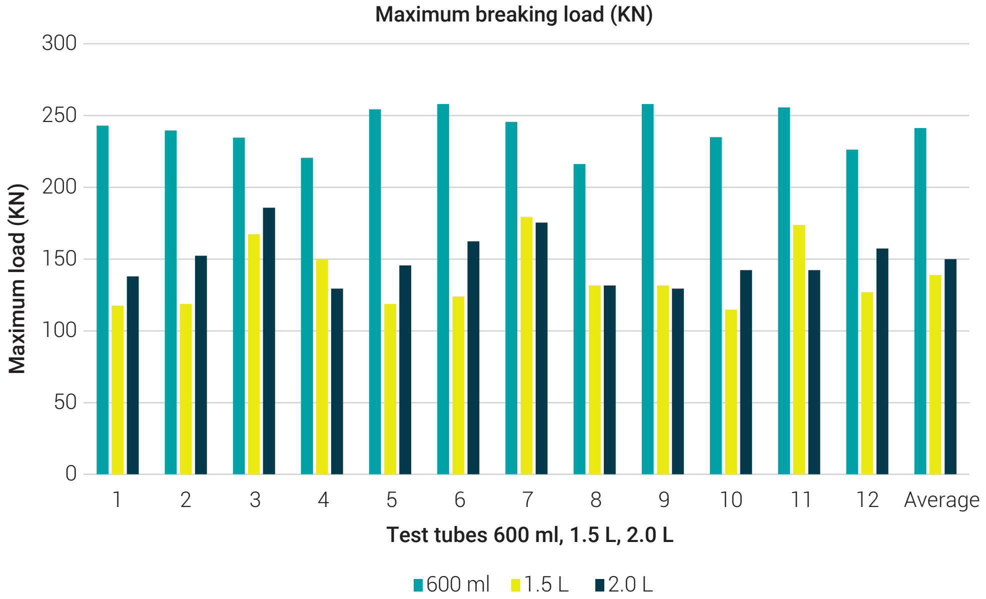
Source: Authors

For 2.0 L bottles, the maximum load supported against compression is 149.725 KN.

Table 8. Maximum resistance to compression for 2 L bottles.

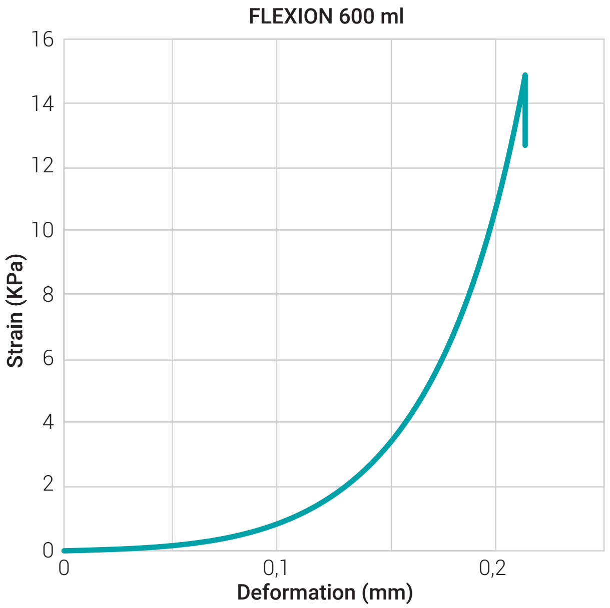
	Maximum load to reach breakdown (KN)
2 L bottles	154,232
	151,920
	143,022
Average load	**149,725**

Source: Authors

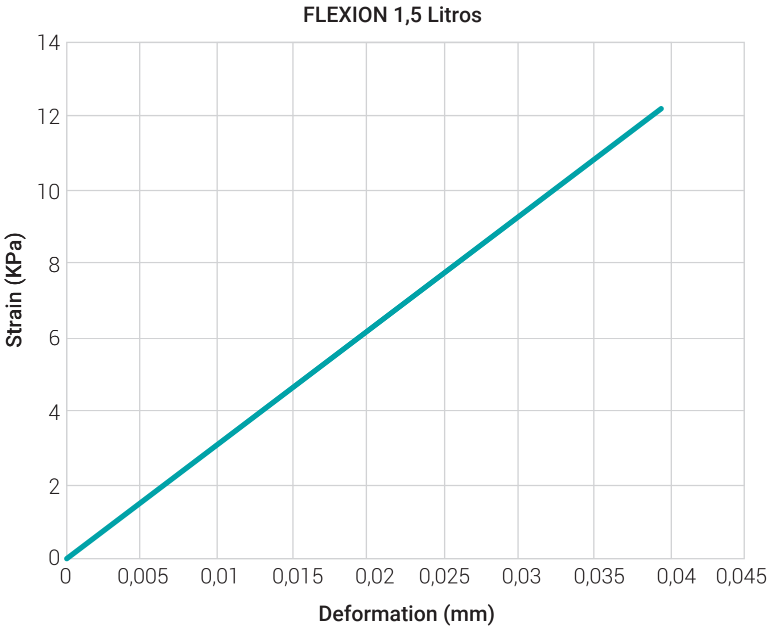


Graph 1. Compressive strength per specimen.
Source: Authors

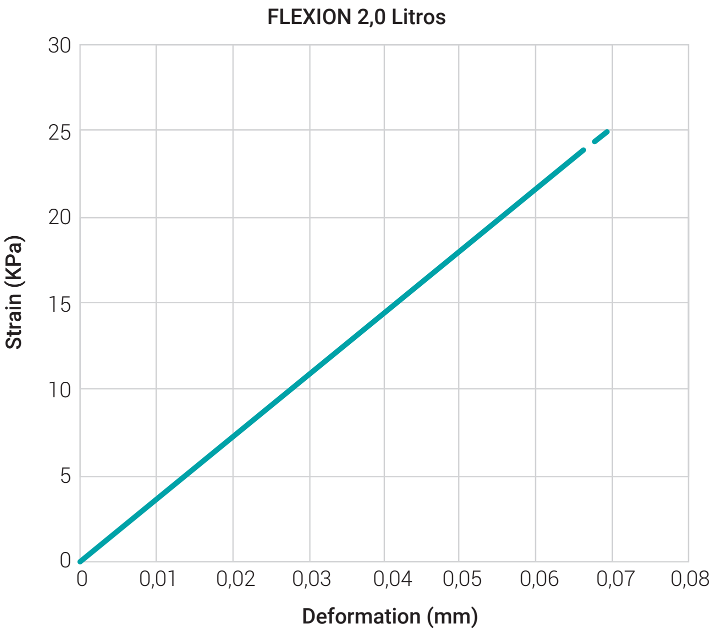
Graph 1 shows the variation of the maximum breaking load in KN, for each of the tested specimens, an average variation between them is presented. The compressive strength for the 600 mm specimens is between 138 KN ≤ breaking load (KN) ≤ 240 KN.



Graph 2. Flexural strength 600 mm specimen
Source: Authors



Graph 3. Flexural strength 1.5 liters specimen
Source: Authors



Graph 4. Flexural strength 600 mm specimen
Source: Authors

According to graphs 2,3,4, the tested specimens met the minimum compressive strength, according to the pre-established procedure for fired clay masonry units according to the procedure determined in the NTC 4017 and NTC 4205 standards.

4. DISCUSSION AND CONCLUSIONS

Table 6, 7 and 8 present the maximum test loads resisted before reaching structural breakdown. The bottles had sizes of 600 mL, 1.5 L and 2.0 L. In the case study, boulder sand was chosen with a particle size range between 0.0625 mm and 2 mm.

In general, the test tubes exhibited similar resistance parameters. The test tube of 600 mL managed superior loads until reaching breakdown than the other scenarios. The experiments show that the breakdown loads vary between 138 and 240 KN.

Observation leads to conclude that the size of the bottles does not have an impact on the loads that can be handled. The behavior of the loads before breakdown showed a proper resistance to the pressure-inducing elements.

The characteristic compressive strength of a brick used for construction is 5.0 MPa for the horizontally drilled masonry unit (brick) according to the technical standard NTC 4205, and, given that this parameter for 600 mL PET bottles is close to 5.2 MPa (before breakdown), the resistance of both materials is not significantly different.

While the weight of a standard brick of roughly 25 × 5.5 × 12.5 cm is 4 kg, a PET bottle of 600 mL filled with sand reaches close to 1.08486 kg. Hence, PET bottles offer an advantage being almost 4 times lighter. The equivalent diameter of PET bottles is 22.5 cm (table 1) which delivers an adequate thermal isolation when filled with sand.

For the 600 ml cylinder, tested, compliance with the minimum compressive strength is established, in accordance with the pre-established procedure for fired clay masonry units according to the procedure determined in the NTC 4017 and NTC 4205 standards.

REFERENCES

[1] UN General Assembly, *Declaración Universal de Derechos Humanos*, pp. 1-6. December 10th 1948, 217 A (III). Taken from: https://www.refworld.org.es/docid/47a080e32.html

[2] UN General Assembly, *Pacto Internacional de Derechos Económicos, Sociales y Culturales. Adoptado y abierto a la firma, ratificación y adhesión por la Asamblea General en su resolución 2200 A (XXI), de 16 de diciembre de 1966*, Naciones Unidas, Serie de Tratados, vol. 993, pp.

3-3, 16 December 1966, disponible en esta dirección: https://www.refworld.org.es/docid/4c-0f50bc2.html

[3] M. Castañeda, Observaciones Generales Aprobadas, *Comité de Derechos Económicos, Sociales y Culturales, México, pp. 1-1. (2015) Available Online: https://www.corteidh.or.cr/tablas/r34177.pdf*

[4] Articulo 51, Derechos sociales, económicos y culturales, Colombia. pp. 1-1 (1991). Available Online: https://www.constitucioncolombia.com/titulo-2/capitulo-2

[5] R. Gómez, Del desarrollo sostenible según Brundtland a la sostenibilidad como biomimesis, Spain. pp. 1-12. (2014) Available Online: https://www.upv.es/contenidos/CAMUNISO/info/U0686956.pdf ISBN: 978-84-89916-92-0

[6] Redacción Economía y Negocios, 36.59% de hogares en Colombia tienen déficit habitacional, Periódico El Tiempo, Colombia. pp. 1-1 (2020) [Online]. Available: https://www.eltiempo.com/economia/desigualdad-y-disparidad-de-vivienda-en-colombia-485296

[7] A. Gutiérrez, 4.7% de hogares capitalinos tienen déficit habitacional y casi 50.000 necesitan una vivienda, Colombia. pp. 1-1 (2020) [Online]. Available: https://concejodebogota.gov.co/4-7-de-hogares-capitalinos-tienen-deficit-habitacional-y-casi-50-000/cbogota/2020-06-18/161529.php

[8] Guajira 360°, Como estamos en vivienda, Colombia. pp. 1-12 (2016) [PDF File]. Available: https://guajira360.org/wp-content/uploads/2016/11/Vivienda.pdf

[9] C. A. García Ubaque y M. F. Gil Hernández, «*Estado del arte sobre vivienda de interés social rural en Colombia. Ajustes normativos desde 1930 hasta 2015*», Rev. vínculos, vol. 15, n.º 1, Colombia. pp. 49–60, may 2018. Doi: https://doi.org/10.14483/2322939X.13006 Available Online: https://revistas.udistrital.edu.co/index.php/vinculos/article/view/13006

[10] R. Gómez, Del desarrollo sostenible según Brundtland a la sostenibilidad como biomimesis, Spain. pp. 15-40. (2014) Available Online: https://www.upv.es/contenidos/CAMUNISO/info/U0686956.pdf ISBN: 978-84-89916-92-0

[11] F. R. Ceja Soto *et al.*, "Sustainability Metrics for Housing and the Thermal Performance Evaluation of a Low-Cost Prototype Made with Poly (Ethylene Terephthalate) Bottles," *Recycling*, vol. 4, no. 3, pp. 30-30, Jul. 2019, Doi: https://doi.org/10.3390/recycling4030030

[12] H. Acevedo Agudelo, A. Vásquez Hernández, y D. A. Ramírez Cardona, «*Sostenibilidad: Actualidad y necesidad en el sector de la construcción en Colombia*», Gest. Ambient., vol. 15, n.º 1, pp. 105–118, may. 2012. Available Online: https://revistas.unal.edu.co/index.php/gestion/article/view/30825 Doi:10.15446/ga

[13] H. Acevedo, A. Vásquez & D. Ramírez, "Sostenibilidad: Actualidad y necesidad en el sector de la construcción en Colombia", Revistas UNAL, Colombia. pp. 1-5 (2012) [Online]. Available: https://revistas.unal.edu.co/index.php/gestion/article/vi%20ew/30825/39307 Doi:10.15446/ga

[14] Ruiz Valencia, Daniel, López Pérez, Cecilia, Cortes, Eliana, & Froese, Andreas. (2012). "Nuevas alternativas en la construcción: botellas PET con relleno de tierra". Apuntes: Revista de Estudios sobre Patrimonio Cultural - Journal of Cultural Heritage Studies, 25(2), pp. 292-303. Retrieved February 10, 2022, from http://www.scielo.org.co/scielo.php?script=sci_arttext&pid=S1657-97632012000200011&lng=en&tlng=es. ISSN: 1657-9763

[15] A. Barragán, K. Figueroa, N. Duran, M Robayo, "Ecobloque estructural para vivienda de interés rural: Un aporte para las comunidades del Alto Magdalena-Colombia", Lámpsakos, no. 17, pp 29- 39, 2017 DOI: http://dx.doi.org/10.21501/21454086.2214

[16] Greenpeace, Colombia mejor sin plásticos: La contaminación plástica en Colombia y el mundo, Colombia. pp. 1-6. (2018) [Online]. Available: http://greenpeace.co/pdf/reporte_plasticos.pdf Doi: https://doi.org/10.1016/S0140-6736(20)30752-2

[17] E. Guzmán, Caracterización de botellas PET para su uso como elementos constructivos de muros de carga. Trabajo de obtención de grado, Maestría en Proyectos y Edificación Sustentables. Tlaquepaque, Jalisco: ITESO. México. pp. 1-10. (2016) Available Online: http://hdl.handle.net/11117/3847

[18] F. Argüello & M. Castellanos, Prototipo de vivienda de bajos recursos con material reciclado (modelación SAP, caracterización de los materiales, animación virtual), Universidad Católica de Colombia, Colombia. pp. 30-45. (2015). Available Online: https://repository.ucatolica.edu.co/bitstream/10983/2423/1/Prototipo-vivienda-bajos-recursos-con-material-reciclado.pdf

[19] A. Solís, Construcción ecológica – casas eco sustentables. Colombia. pp. 1-20, 2021 [PDF File] Available Online: https://refugiodelamontana.com/wp-content/uploads/2021/11/casas.pdf

[20] J. González, Análisis y mejora de elementos y sistemas constructivos estructurales. Arquitectura, Universidad UPM, Colombia. pp. 1-10. (2019) Available Online: https://oa.upm.es/54207/ Oai:oa.upm.es:54207

[21] N. García, et al. "Propiedades físicas y mecánicas de ladrillos macizos cerámicos para mampostería, Ciencia e ingeniería neogranadina", Vol. 22-1, Colombia. pp. 43 - 58, junio de 2012, ISSN: 0124-8170 Available Online: http://www.scielo.org.co/scielo.php?script=sci_arttext&pid=S0124-81702012000100003

[22] C. Sarango & M. Cisne, Análisis del sistema constructivo con botellas recicladas PET, y su aplicación en el diseño de un centro de exposición y capacitación para la Planta de Reciclaje de la ciudad de Loja. Colombia. pp. 1-25 (2013) (Tesis de Arquitectura). UTPL. Loja. Available Online: http://dspace.utpl.edu.ec/jspui/handle/123456789/7663

[23] Arquitectos sin fronteras, Manual de construcción con botellas de plástico, Guatemala. pp. 1-4 (2011). Available Online: https://asfes.org/galicia/RecursosEducativos/Unidades_Didacticas/Construimos_Reciclamos/Manual_construccion_botellas.pdf

[24] C. Reyes, El PET como sistema alternativo para la construcción de muros en la vivienda, Universidad Autónoma Metropolitana, México. pp. 1-30 (2013) Available Online: http://hdl.handle.net/11191/5519

[25] Afanador García, Nelson, Guerrero Gómez, Gustavo, & Monroy Sepúlveda, Richard. (2012). PROPIEDADES FÍSICAS Y MECÁNICAS DE LADRILLOS MACIZOS CERÁMICOS PARA MAMPOSTERÍA. *Ciencia e Ingeniería Neogranadina*, *22*(1), pp. 43-58. Retrieved February 15, 2022, from http://www.scielo.org.co/scielo.php?script=sci_arttext&pid=S0124-81702012000100003&lng=en&tlng=es.