Characterization of a polypropylene and polyethylene compound for the production of bricks in non-structural walls

Caracterización de un compuesto de polipropileno y polietileno para la producción de ladrillos en muros no estructurales

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ABSTRACT

This paper investigates the feasibility of using recycled plastic composed of polypropylene (PP) and high-density polyethylene (HDPE), as a basis for the fabrication of plastic bricks for non-structural walls starting from the material characterization. The deformation properties of plastic bricks were evaluated under the application of compression, flexural and traction forces; the thermal analysis of the material was carried out by means of the ignition test, differential scanning calorimeter (DSC) and its water ab-sorption capacity was also tested. Satisfactory results were obtained in the tests carried out; It was found that the compressive strength of the material complies with the requirements of standard specifications for conventional bricks (clay - concrete), and the physicochemical properties of the composite meet specifications of material for use in non-structural walls; which makes it an innovative material with enormous potential for use in the construction sector.

Keywords: polyethylene; polypropylene; compressive strength; flexural strength; ecological bricks.

RESUMEN

Este artículo investiga la viabilidad en el uso de plástico reciclado compuesto de polipropileno (PP) y polietileno de alta densidad (HDPE), como base para la generación de ladrillos en muros no estructurales a partir de la caracterización del material. Se evaluaron las propiedades a deformación bajo la aplicación de esfuerzos de compresión, flexión y tracción; se determinó la resistencia al fuego del material mediante el ensayo de inflamabilidad, y se evalúo su capacidad de absorción de agua. Se obtuvieron resultados satisfactorios en los ensayos realizados; se encontró que la resistencia a la compresión del material cumple con los requisitos exigidos en la norma de ladrillos convencionales (arcilla – concreto), y las propiedades físico- químicas del compuesto cumple como material para el uso en muros no estructurales; lo que lo convierte en un material innovador y con un enorme potencial en el sector de la construcción.

Palabras Clave: polietileno; polipropileno; resistencia a compresión; resistencia a flexión; ladrillos ecológicos.

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1. INTRODUCCIÓN

Global overpopulation, consumer society, and lack of sensitivity to the environment have led society to an environmental crisis aggravated by excess waste dumped in natural sources without any control (1-3). If current consumption patterns and management practices continue, by 2050 there will be around 12,000 million tons of plastic garbage in landfills and natural spaces (4, 5).

The Colombian government has proposed different regulations that encourage recycling of industrial waste, but to date, only 17% of the total waste generated is recycled, and there are no established waste separation programs in most cities (6, 7). Colombia shows very low rates of use and recovery of waste, and some cities such as Bucaramanga, Armenia, Manizales and Neiva, in addition, have problems because their final waste disposal sites tend to exhaust capacity (8).

The main problem of plastic waste in cities arises from the difficult degradation of plastic in the environment. It is estimated that plastic takes approximately 100 to 1000 years to decompose, generating accumulation on a human time scale (6, 7). Reuse is an alternative to take advantage of these wastes, and counteract negative effects caused by their misuse and poor final disposal. A group of potential polymers for recycling could be polyethylene and polypropylene, which are the largest fraction in the plastic waste stream (9). It is because of the above that recycled plastic for homes becomes an important model for sustainable waste management (1).

Different authors have conducted research evaluating the use of polymers for the generation of building elements, in order to make optimal use of these residues. Maddah (10) made a review of poly-propylene, showing that it is a versatile plastic, with the lowest density of all plastics of 0.90 g / cm, with high rigidity, high resistance to bending, impact, heat and low water absorption. On the other hand, the research carried out by the Eco-brick company, concluded that materials made with recycled plastic have advantages over conventional ones due to their low density, condition ideal for being implemented in non-structural systems used in the construction of walls, partitions, Interiors, and ceilings (11).

Andreas Froese introduced a new technique called Bi4PVS which consists of the use of bottles with recycled PET (Polyethylene Terephthalate) to create bricks as a construction material. This new methodology is considered as more durable, resistant, low-cost, friendly to the environment and has been implemented in several countries such as Nigeria, South Africa, Norway, the Philippines and India (12).

Valinejad Shoubi, et al. (13) concluded in their research that plastic used as a construction material can have substantial effects on energy saving. Using this material instead of bricks, reduces CO₂ emissions, by reducing the percentage of cement used in its manufacture. Turku (14) evaluated the durability of the wood-plastic composite after being subjected to water absorption processes, accelerated aging of xenon arc light and freeze-thaw cycles. The research concludes that when using recycled plastic, the mechanical properties of traction and bending showed a decrease of 2-30% with respect to virgin plastic. Barroa et al. (15) study about the feasibility of using limestone and polyester resin for the generation of an ecological brick, they found that the greatest resistance to compression is obtained when a higher pro-portion of polyester resin is used. This confirms that when using polymeric elements, higher resistance is achieved, due to the ductility of these materials before failing. They also carried out water absorption and flammability tests, obtaining a fairly low absorption percentage. Regarding the flammability results according to ASTM D635, it was observed that the purely polyester resin samples tended to spread the flame, which was not the case with the limestone / resin samples.

J.O. Akinyele et al. (16) conducted a study on the feasibility of using PET material combined with clay for the generation of fired blocks, concluding that the optimal proportion of PET material is 5%, and it was determined that larger proportions caused problems in its structure.

Martínez and Cote (17) proposed a brick design based on cement and PET flakes, making samples with different amounts of material to define the mechanical behavior with each one. Initially, samples with amounts of 80 to 90% of cement in ratio of its weight was discarded, due to low percent to PET used; and then they found that by using an equal proportion of cement and PET, the proposed brick achieves strengths very similar to commonly used bricks.

Salazar et al. (1) carried out a project focused on the use of waste plastic materials for the assembly of a housing module, for which they performed tests of mechanical resistance, thermal, acoustic conductivity and permeability; obtaining a compression resistance greater than that obtained in traditional materials such as concrete. Divergence of the resistance obtained with different plastic samples was found, and this behavior was attributed to the presence of voids generated by extrusion.

Given the above conditions, the present research characterized the mechanical and physicochemical properties of a polyethylene and polypropylene compound, defining compliance with the acceptable limits for its use in non-structural bricks.

2. MATERIALS AND METHODOLOGY

The specimens were supplied by the company Madera Plástica de Colombia, and these specimens are made up of the following proportions: 76.7% polypropylene (PP), 18.63% high-density polyethylene (HDPE), 4.67% additives; with a size of the particles were between 7mm and 12mm after grinding. The material is subjected to the processes of selecting, cleaning, and grinding to finally obtain specimens by the extrusion method with the dimensions required for different tests.

Extrusion molding consists of initially preparing and grinding the material to place it in a hopper in the indicated proportions. Then, the selected material is transported by a helical screw that is surrounded by a heating chamber, allowing the material to melt as the mixture is generated; and finally, the generated compound passes through the nozzle of the mold, giving the final shape to the compound (18).

To evaluate the behavior of the polypropylene and polyethylene compound, compression, flexural, traction, flammability, absorption, and thermal analysis tests were carried out. In the compression tests, 10 samples of 5cm of length with section of 2.5cm x 2.5cm were used. In the flexural tests, 10 samples of 8cm of length with a section of 1cm x 2cm were used. For the tensile test, 5 samples of 11cm length with a section of 2.5cm x 1.5cm were tested. For the flammability test, 5 samples were used with a length of 15cm, with a section of 2.1cm x 1.2cm. In the absorption test, 5 samples of 7.6cm in length were used, with a section of 2cm x 2cm; and for the thermal analysis, 2 samples of 12mg were used.

2.1. Mechanical and physicochemical properties

Figure 1 shows a specimen tested with its cross section before and after test. For the evaluation of the mechanical properties of the material, the Universal Shimadzu AGS-X machine from the Structure laboratory of the Surcolombiana University was used, and the specimens were tested according to the regulations required in each case. In the compression test, 10 specimens were tested as stipulated in ASTM D 695-15 Standard Test Method for Compressive Properties of Rigid Plastics (19). For the bending test, 10 specimens were used according to ASTM D 790-03 Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials (20), and for the tensile test, 5 samples were tested according to ASTM D 638-14 Standard Test Method for Tensile Properties of Plastics (21).

For evaluation of the physicochemical properties, the flame propagation test, Differential Scanning Calorimeter (DSC) and the absorption test were carried out. The flame propagation test was carried out on 5 specimens in the EATIC Laboratory of Grupo EPM in the city of Medellín, under the ASTM D 635-18 Standard Test Method for Rate of Burning and / or Extent and Time of Burning of Plastics in a Horizontal Position (22). For the Differential Scanning Calorimeter, 2 groups of samples were tested, some for analysis and others for reference in the EAFIT university laboratory according to the ASTM D 3418-15 (23) and the water absorption test was established for an immersion period of 24 hours, testing 5 specimens according to the ASTM D 570 Standard Test Method for Water Absorption of Plastics (24).



Figure 1. a) Composite of polypropylene and polyethylene tested; b) Cross section before a test; c) Cross section after compressive failure.

2.2. Methodology

To carry out the research work, the procedure shown in figure 2 was considered. The results obtained in the lab-



Figure 2. Research methodology.

oratories (Compression-Absorption) were compared with the requirements established in the standard NTC 4205 Masonry units of fired clay, bricks and ceramic blocks (25) which defines the minimum requirements for non-structural masonry units.

The compression test was carried out according to the procedure defined in the ASTM D695-15 standard at a speed of 1.27mm/min; the flexural tests were carried out following the guidelines of the ASTM D790-03 standard applying a load at a speed of 1.4mm/min; the tension tests were carried out according to the procedure presented in the D638-14 standard, applying a speed of 0.5mm/min; the Absorption tests were carried out according to the ASTM D570-98 standard. The flammability test was carried out according to ASTM D635-18, which allows to determine the ignition time, the burning rate, and the heat release of plastic samples in a small-scale horizontal position, at a distance of 20 ± 1 mm with time. 30 second ignition; 5 specimens were taken with approximate measurements of 15 cm long, 2.10 cm high and 1.20 cm thick.

Thermal analysis of the HDPE samples was carried out by means of Differential Scanning Calorimeter (DSC) tests, according to the procedure outlined in ASTM D 3418-15. This test makes it possible to determine the amount of heat that a material absorbs or releases when it is subjected to changes in temperature at a constant rate. To carry out the tests, 12 \pm 1 mg of HDPE material were weighed by means of an analytical balance, then each one of the samples was placed in hermetically sealed containers, and placed in the differential scanning calorimeter (DSC) from TA Instruments Q200; The test consisted of heating the samples from 0 ° to 200 °C at a constant heating rate of 10 °C/min in a helium atmosphere with a purge rate of 70 ml/min.

3. RESULTS AND DISCUSSION

3.1. Compression properties

Figure 3 shows the deformation suffered by the specimens HPPE-PP compound under a constant compression force

as a function of time. As can be seen, the figure 3 shows a typical curve of a flexible plastic (26) that is characterized by having a first section of curve in a proportional region between stress-strain, in which the deformations are relatively small and are associated with the extension of the existing bonds between the atoms of the plastic molecules; then, it passes to a region where the material still behaves as elastic and its deformations are a consequence of the stretching of molecules that are wound on themselves, so the deformation is recoverable, although not instantaneously; finally, the curve shows a region where the deformations are no longer recoverable, since they are a consequence of the sliding of some molecules with respect to others.

Each specimen was subjected to axial compression load to failure, recording ultimate resistance. During the test it was determined that the compressive strength of the HDPE-PP compound varies between 21.3 MPa and 25.6 MPa with an average of 23.40 MPa, finding resistance values higher than those reported in other studies. Some authors have carried out similar test on materials with different characteristics; Alkine (2020), evaluated the resistance of compression of bricks of clay with 5% Polypropylene terephthalate (PET), finding a compression resistance average of 2,3 MPa (16); on the other hand, Martinez (2014) evaluated a materials with a composited 50% of cement and 50% of PET, finding than a compression resistance average of 2,39MPa (17); Archila (2017), tested recycled plastic wood through compressions tests, finding a resistance average 8,92MPa (27); and Flores (2019), carried out a characterization of the PET material as a material for masonry, reaching a compressive strength of 10.78 Mpa (28).

In Figure 4, the results obtained from the compressive strength for each test specimen were compared with the strength of non-structural fired clay bricks and concrete. Table 1 shows the minimum values reequipments for compressive strength for non-structural masonry units, as established in the Civil Engineering and Architecture Standard for fired clay masonry units (NTC 4205-2). Where



Figure 3. a) Load-displacement curves for HDPE specimens tested; b) Compression compound failure.

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Figure 4. Comparison in the compressive strength of bricks made of HDPE, Fired Clay-VD, Fired Clay-M and Concrete.

HHB: Horizontal Hollow Bricks, VHB: Vertical Hollow Bricks, and SB: Solid.

Fable 1: Minimum value	es of $f'c$, acco	ording to NTC	2-4205.
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Туре	Compression Strength Mpa (kgf/cm²)		
	Average 5 u	Unit	
ннв	3.0 (30)	2.0 (20)	
VHB	14.0 (140)	10.0 (100)	
SB	14.0 (140)	10.0 (100)	

As can be seen in table 1, for a vertical hollow bricks unit, the regulations require a minimum compressive strength of 10 MPa; According to the results of the tests carried out, the compressive strength of the HDPE-PP compound complies with all the specimens tested individually, indicating a high degree of compressive strength of the material. The above since this material is made of polyethylene, which provides better mechanical properties by having a higher density

3.2. Flexural properties

For this test, 10 specimens were taken, of which, half were tested on the axis of greatest inertia (longitudinal axis) and the other half on the axis of least inertia (transverse axis).

The tested specimens were subjected to bending stresses at speed of 1.40 mm/min to determine their behavior and resistance to breakage; the results obtained are in the range of 15.06 MPa and 22.35 MPa, with an average value of 18.04 MPa for the section with the least inertia and a standard deviation of 2.95. For the section with the greatest inertia, values between 19.34 MPa and 24.68 MPa were obtained, with an average value of 21.20 MPa and a standard deviation of 2.20 with a confidence interval of 95%. Bearing in mind the above, it is assumed that the population from which the sample comes can be represented by the normal distribution. Higher flexural strength results were obtained compared to those reported by other authors, such as in Akinyele et all, 2020 who determined flexural strength values of 11.96 MPa for a dosage of 5% sodium terephthalate. polyethylene in addition to clay in fired bricks(16).

Regarding the research by Archilla et al, 2017 in recycled plastic wood specimens composed of high- and low-density polyethylene, results were obtained for bending stresses on the side with the least inertia of 13.01 Mpa (27). The conclusions reached Londoño & González Villa, 2009 indicate that for materials composed of low-density polyethylene, flexural strengths are reached on the longitudinal side of 14.01 MPa and on the transverse side of 11.61 MPa, with the values being much higher than the results achieved in this research, which indicates that the material composed of high-density polyethylene HDPE is an indicator of great rigidity and resistance (18). On the other hand, Flores (2019) determined that the flexural strength of PET as a material for masonry reaches a flexural strength of 126.7 MPa, finding higher values than those found in the present study (28).

The flexural strength should theoretically vary between 10% and 30% of the compressive strength (29), and the minimum compressive strength per unit according to NTC 4205 for non-structural masonry is 10 MPa. Bearing in mind the above, it is established that the minimum value of resistance to bending of the tested material must be 3 MPa. Therefore, it can be deduced that all the study specimens complied with the minimum required, given that the minimum flexural stress obtained was 15.1 MPa and the maximum was 24.7 MPa; this indicates that the material has a high rigidity when faced with the request of different loads applied perpendicular to its longitudinal axis (see figure 5).

According to Figure 5, the stress-strain relationship is established for each tested specimen. A characteristic behavior of elastic solids that store a certain amount of energy when subjected to minor stresses is detailed; while with a higher effort, they continuously deform like a fluid (30). In Figure 6, the results obtained from the flexural strength for the 10 specimens tested with non-structural fired clay bricks were compared to those of HDPE



Figure 5. Load-displacement curves for HDPE specimens tested in flexure with failure of the compound to flexion; a) smaller section; b) larger section.



Figure 6. Flexural strength of bricks made of HDPE and PV fired clay.



Figure 7. a) Load-displacement curves for the HDPE specimens tested in tension; b) Application of tensile forces; and c) Breakage.

3.3. Tensile properties

This test applies the load perpendicular to its plane to equalize the behavior against similar stresses, generating bends parallel and perpendicular to the direction of the load, allowing to determine the maximum resistance achieved by the HDPE-PP compound before breaking. Figure 7b and 7c shows the procedure carried out to failure of the tensile test specimens.

According to figure 7a, two phases can be distinguished. At first, their stress-strain relationship has a linear elastic behavior, and then a loss of rigidity is observed until failure is reached, it is at this point, where the ductility of the material is reduced as that the load and the tensile modulus increase

It was found that the HDPE-PP compound has a tensile strength that is with a maximum value of 12.98 MPa and a minimum of 11.46 MPa. Its average of 12.20 MPa can be classified according to Méndez y Coreño as a flexible plastic, however, the determined elastic modulus of 590.75 MPa is considered to be high (31). The foregoing is presented by the interaction of the two polymeric materials that form the compound. On the one hand, polypropylene is characterized

by its flexibility and mechanical resistance, and on the other hand, high-density polyethylene is characterized by having greater hardness and rigidity, thus allowing the compound to reach a high modulus.

The studies done by Pluiim were taken as a reference, in which he found tensile strength values that ranged between 1.5 and 3.5 MPa for clay and calcium silicate bricks (32). On the other hand, according to the experimental results of Sanchez and Mejía for conventional clay blocks, the value is between 0.35 and 1.4 MPa (33). The tensile strength results obtained in the HPDE-PP compound test are much higher than those presented by Pluijm and Sanchez, which represents the difference in the flexibility properties of masonry with respect to polymers (32, 33).

3.4. Flammability test

The flammability test allows analyzing the behavior of the HDPE - PP compound with respect to exposure to fire. Figure 8 shows the procedure that was carried out on the flammability test. Figure 8a presents the initial test conditions, and figure 8b show Drip start, flame withdrawal and determination of fire propagation/burning speed.



a)

Figure 8. Flammability test procedure. a) Initial test conditions, b) Start drip and determination of fire spread.



Figure 9. Flammability test results. a) Burning rate; b) Ignition time.

According to Hilado, 1968 one of the most important characteristics of plastics is the propagation of the flame, which can be defined as the speed of movement of a flame front under certain combustion conditions (34). This characteristic provides a measure of fire risk, since the spread of the flame on the surface can transmit fire to more flammable materials in the vicinity and, therefore, enlarge a conflagration. The flame spread of a material can be measured according to the burning rate, the burning distance of the flame, the flame spread factor and the height of the flame. Figure 9 shows the combustion rate and the ignition time for the 5 tested specimens.

According to the results, when the combustion reaches 25mm, the ignition time count starts and ends when it reaches a length of 100mm. The average burning speed obtained for the five samples was 9.64 mm/min; none of the samples tested self-extinguished, and continuous dripping was observed in all. The flame passed the 25 mm benchmark within 150 seconds in all samples, reaching an average ignition time of 505.2 seconds. The highest ignition time and the lowest burning rate show that the material can be classified as low flammability according to Suharty et al. (35).

3.5. Absorption test

Figure 10 shows the minimum absorption percentage for test piece 1 of 0.0436% and the maximum for test piece 2 of 0.4359%, with an average of 0.19%. This is related to the properties that characterize the HDPE material, as is non-hygroscopic, that is, water does not penetrate the material and remains on the surface. The variability in the results obtained is related to the internal structure of the material, the porosity present in the specimens is not uniform and varies according to each specimen tested.

The results of water absorption tests were relatively negligible, and this makes a material ideal for high humidity environments, because the increase in the mass of sub-merged water during the immersion time is minimal and does not affect its internal structure. According to Martínez et al. the absorption of water in materials constitutes a determining factor that limits its usefulness for construction, since this phenomenon can generate great dimensional deformation under the action of water (36).



Figure 10. Results of absorption tests on HDPE specimens.

On the other hand, the absorption results found in this study are similar to those reported by Krutibash et al (2020) who found that the absorption varies between 0.03% and 0.279% for compounds of 70% PP and 30% a glass/jute/sisal fiber (37). The results of the absorption test yielded values similar to those reported by Flores (2019), who found that the PET compounds yielded an absorption percentage of 0.27%, finding values similar to those found in this study (28).

Table 2. Maximum Absorption Values, according to NTC 4205.

Туре	Water Maximum Absorption %				
	Interior		Exterior		
	Average 5 u	Unit	Average 5 u	Unit	
HHB	17	20	13,5	14	
VHB	17	20	13,5	14	
SB	17	20	13,5	14	

Table 2 shows the maximum values of water absorption (%) in 24 hours of immersion, for non-structural masonry units in interior and exterior use, according to the provisions of the Civil Engineering and Architecture Standard for masonry units of fired clay (NTC 4205-2). Where HHB: Horizontal Hollow Bricks, VHB: Vertical Hollow Bricks, and SB: Solid Bricks. According to the results obtained and when comparing with the water absorption requirements in 24 hours of immersion (average and individual maximum) of table 2, all the tested specimens are below the maximum values required in NTC 4205, which makes this material ideal for indoor and outdoor use (facades), as it will have good resistance to weathering, as it has high durability and resistance to atmospheric agents.

3.6. Thermal analysis

Figure 11 shows two peaks that show the solid-liquid phase transition and represent endothermic thermal events related to the melting points of two different materials that make up the sample. The first melting point corresponds to a temperature of 132.78 ° C, and the second is reached at a ap-proximate temperature of 161.8 ° C. The first melting point (132 ° C) is related to the melting temperature of HDPE and the second melting point (161.8 ° C) is related to the melting of poly-propylene. The results obtained in the thermal analysis coincide with that reported by Sutar et al. (2018) (38), who determined the DSC properties for specimens with different compositions of HDPE with PP; concluded that with a dosage of 80% HDPE and 20% PP, there are melting points of 134.8°C for HDPE and 162.2°C for PP. This behavior is due to the fact that PP crystallizes faster than HDPE, therefore, it slows down the nucleation of polymeric compounds.



Figure 11. DSC curves for HDPE and PP composite.

In Figure 11 it is observed that, at a temperature of 80 ° C, a glass transition begins that is common in amorphous polymers, that is, polymers whose chains are not defined according to a crystalline ordering. That is, after 80°C, the compound becomes rubbery, losing its mechanical resistance properties. Asensio (2018) affirms that, by exceeding the glass transition temperature, the molecules change their hardness, density, rigidity and percentage of elongation; and each material has a different glass transition temperature, as it is an intrinsic property of each one (39).

On the other hand, according to the results of Figure 11, it is concluded that the material does not show degradation processes for a temperature range from 0 $^{\circ}$ C to 200 $^{\circ}$ C.

4. CONCLUSIONS

The characterization of the material composed of polypropylene and high-density polyethylene (HDPE-PP) was carried out. Tests were carried out to know the mechanical properties of the material where satisfactory results were obtained. It was found that the HDPE-PP material has a great mechanical resistance, this is mainly due to its composition, as it has a higher percentage of Polypropylene, which improves the mechanical properties. In the compression test, a minimum stress of 21.3 MPa and a maximum of 25.55 MPa were obtained, exceeding by more than 200% the minimum established in NTC 4205 of 10 MPa, the results were higher than that required for masonry of conventional materials such as clay and concrete. In the flexural test, a minimum stress of 15.06 MPa and a maximum of 22.35 MPa are obtained in the direction of greatest inertia (longitudinal axis), exceeding the minimum bending resistance range by 501.97%. Likewise, for the tensile test of the compound, values of 11.46 MPa to 12.98 MPa were reached, being in the range for flexible plastic and showing better results than conventional clay bricks, therefore it is deduced that the material HDPE- PP will perform well under different load requests.

In the flammability test, the material tested showed a tendency to spread the flame because it does not self-extinguish and generates constant dripping, therefore under operating conditions it can be considered as a fire transmitter, however, it is a variable that can be controlled with the use of fire-retardant additives that improve their performance. The DSC test analyzed the behavior under a controlled temperature range (0 to 200 °C) relating the melting points of each material that is part of the compound and the glass transition typical of amorphous polymers.

As for the absorption test, low values were obtained, in a range with a minimum value of 0.043% and a maximum of 0.436%, which makes the HDPE-PP material ideal for outdoor uses, as it will have high durability and good resistance to weathering.

Having met the minimum requirements established in NTC 4205 for the resistance of conventional bricks, it is concluded that the HDPE-PP material is a viable option for the reuse of plastic waste as an alternative to be implemented as materials for brick construction. of non-structural systems, and is a viable alternative to the increasing degree of pollution produced by these wastes.

The use of HDPE-PP can be a solution to the housing deficit currently facing the country, as it has good compressive strength, good flexural strength, good traction properties, moderate fire behavior and low absorption which makes it very efficient.

The tests were carried out on specimens with smaller dimensions than those specified for clay units, for which it is recommended to carry out the test in units with the same dimensions, although a very good behavior would be expected from the results shown. In addition, the present research work leaves an open field for future academics and researchers to broaden the field of characterization of the HDPE-PP compound, and verify the results of the present study.

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