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Technical and economic comparison between recycled plastic and hydraulic concrete pavers

Comparación técnica y económica entre adoquines fabricados con plástico reciclado y con concreto hidráulico

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Abstract
Research regarding the use of solid recovered materials for building is becoming popular worldwide. The objective of this project was to determine the technical and economic resistance and efficiency of pavers made from recovered plastics compared to those made with hydraulic concrete, subject to current regulations. The technical and economic results were favorable for the research.
Keywords: prefabricated pavers, recycled materials, project management, environment, innovation

Resumen
La investigación sobre el uso de materiales sólidos recuperados para la construcción se está volviendo popular en todo el mundo. El objetivo de este proyecto es determinar la resistencia técnica y económica y la eficiencia de los adoquines hechos de plásticos recuperados en comparación con los hechos con concreto hidráulico, sujeto a las regulaciones actuales. Los resultados técnicos y económicos fueron favorables para la investigación.
Palabras clave: adoquines prefabricados, materiales reciclados, gestión de proyectos, medio ambiente, innovación.

1. Introduction

Globally, environmental organizations, national authorities, governmental and non-governmental organizations created for environmental conservation and protection, trade associations, educational centers, basic training

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schools, colleges and universities, are carrying out educational and pedagogical campaigns aimed at transforming the *modus vivendi* of the inhabitants of urban and rural areas, in order to change habits in the face of solid waste management issues, especially that of plastic products, such as PET (Polyethylene Terephthalate), high and low density Polyethylene, Polypropylene, Styrene, etc.

The production of waste has become a global problem and its solution is key for human survival. Some of this waste comes from plastics, cement, hospitals, garbage collection, food production and consumption industries (Emmanuel, Perrodin, Keck, Blanchard & Vermande, 2005; Van, Rößler & Bui, 2014). Fortunately, several of these discarded products are biodegradable and can be easily transformed into other useful products. Unfortunately, several products are difficult to biodegrade, they have increased exponentially, and their effect on the environment is unpredictable. Every year, 300 million tons of plastics are produced worldwide (Halden, 2010). Overtime, research in developing countries to create strategies to mitigate contamination with these reusable polymer residues has increased (ALESMAR, RENDON & KORODY, 2008; Di Marco Morales, León Téllez & Almeira, 2016; Cabo Laguna, 2011; Flores, Rojas, Torres, Vallejos, Flores & M., 2014). Reddy, Chandra Kumar & Asadi (2019) used low density polyethylene bags (LDPE or PE-LD) as a total cement replacement to prepare plastic paver bricks with good results in compressive strength, melting point and water absorption. Constantin, Shitote, Abiero Gariy & Ronoh (2019) used waste plastic bags to completely replace conventional cement in concrete pavement blocks and improve desired properties for road pavement. Pavement blocks made with LDPE plastic and sand wastes, with a 5% coarse aggregate, showed better mechanical properties, flexibility and resistance to water absorption. Thousands of tons of waste are dragged into rivers and oceans, greatly damaging flora and fauna, as well as ecosystems that are fundamental to breed and preserve coral species, algae and fish in different ecological contexts. Tulashie, Boadu, Kotoka & Mensah (2020) tried turning plastic waste into pavement blocks in Ghana, and determined the physical and chemical properties of well sand, sea sand, plastic waste and building blocks. The increase in plastic composition improved the average penetration resistance of both pavement blocks, and results suggest that turning plastic waste into pavement blocks is feasible and can help reduce the rapid accumulation of waste in Ghana.

Educational and pedagogical campaigns in Colombia, as elsewhere, are increasingly constant; environmental policies are being directed to the regulation, use, management and recovery of solid waste of industrial origin; thousands of companies and microenterprises are making systematic use of polymers that can be recovered and processed as raw material for industrial use. Universities have developed research focused on studying the technical feasibility of using these recyclable materials as an alternative for the construction of environmentally friendly structural elements (Sierra Jiménez, 2016; Di Marco Morales, León Téllez & Almeira, 2016; Álvarez & Calderón, 2001; Di Marco, 2014; Serrano-Guzman & Perez-Ruiz, 2011).

The purpose of this study is to compare the technical and economic nature between pavers made of recycled plastics and pavers made with hydraulic concrete. It also aims to publicize the benefit and reliability of the articulated pavement made with discarded polymers, which can be recovered and processed for this purpose. In addition to seeking to favor the environment, mitigating pollution, it is intended to verify that recycled material can generate an economic benefit; that it is resistant and durable and that it can contribute greatly to populations with little State investment in infrastructure and equipment, specifically on matters of improvement and recovery of pedestrian and vehicular roads of low transit.

Professor Juan Zamora of Mexico's UPAM (Brunoticias, 2018) mentions that PET provides a resistant piece with a duration of more than 20 years, subjected to weather conditions and mechanical efforts. It has several advantages because it is a polymer, and consequently has long-lasting characteristics, since it does not disintegrate easily in the environment.

There are numerous proposals that seek to repurpose plastic waste to reduce the costs of construction of popular homes. The manufacture of concrete bricks with a significant percentage of crushed plastic or polyethylene or PET fibers marks the tendency to mitigate environmental pollution with waste, as shown by the project proposed by students of the University of Piura (Pastor Castillo, Salazar Oliva, Seminary Regalado, Tineo Camacho & Zapata Valladolid, 2015). These students identified the properties and characteristics of each polymer, made a detailed study of the problems generated by waste and its contamination in the Peruvian territory, and proposed how to design and manufacture bricks adding plastics, sand and cement to reduce costs and to increase the benefits for both housing projects and the environment.

On the question regarding the economic favorability of pavers manufactured from recycled plastic, an investigation by students of the Catholic University of Colombia (Piñeros Moreno & Herrera Muriel, 2018) shows a comprehensive study on the economic feasibility for the manufacture of blocks with recycled plastic aggregates, generally Tereftalato de Polietileno (PET), in the construction of houses. The document addresses the issue of plastic waste contamination and a solution is proposed: manufacturing low-cost blocks for the construction of houses, and for general uses in masonry.

The interest in the use of recycled plastic encourages researchers, students and environmentalists to search for possible solutions that benefit the construction sector and to mitigate the environmental impact in order to know more about the subject of this research, about the advantages and disadvantages of pavers made from recycled plastics. Guerrero (2015) establishes concepts and discusses the advantages and disadvantages of this product. Despite several disadvantages, the product is very useful and economically favors its users.

Regarding resistance studies carried out on pavers manufactured with different PET percentages, in the conclusions of the investigation carried out by civil engineer Raúl Di Marco (Di Marco, 2014), shows that pavers manufactured with PET comply, in accordance with NTC 121, with the absorption percentage (below 7% according to the standard average value). It also shows that the Modulus of Rupture (Mr) with PET additions between 20% and 25% significantly reduces the amount of sand, which results in an economic benefit.

Regarding the economic comparison between the pavers made from recycled plastic and rigid concrete pavers for articulated pavement, Sheila Álzate & Fanny Tafur's (2006), from the University of La Salle, show the project's viability. However, it is clear that the cost of the paver with recycled plastic depends on the support given to the manufacturer once the rigid concrete paver is found at lower prices.

Taking into account the study done in Colombia (2015), it is not possible to make pavers with recycled PET once large companies such as ENKA S.A. (ENKA DE COLOMBIA S.A., 2015) buy this product at a favorable cost for the recycler, thus increasing the raw material for pavers. Large-scale mass production requires a significant amount of plastic: between 1 and 1.3 kg of crushed plastics are needed to make each paver. If this raw material is not processed by the manufacturer, it must be purchased at around \$2300 to \$3600, which means that the production exceeds the expectations of the final consumer. This research has found an alternative that would greatly help in the use of recycled plastic for the manufacture of pavers, the handmade manufacture of the plastic crushing machine, and the manufacture of an extruder for the thermo-processing of plastic: Making the necessary equipment through manual labor, production costs are reduced significantly. The procurement of the raw material would initially be proposed to the leaders and low-income communities to recycle plastic (polyethylene and polypropylene), buying it at an average price of \$300 per kilogram. This could allow a very important profit for the producer and the final consumer, making it a viable and economically profitable option.

According to the research carried out, there is a special emphasis on PET use in the manufacture of blocks with sand and cement for the construction of houses and paving stones for articulated pavement. This study makes the economic comparison of pavers made with polyethylene, the most used polymer in the industry:

Polyethylene can be found in plastic bags, container lids, liquid detergent or shampoo containers, and in most packaging of everyday use products. Against rigid concrete pavers, polyethylene is the most abundant plastic waste in the country. PET is recycled for the manufacture of fibers that are then used in the clothing manufacturing industry, fretwork, soda bottles. This generates juicy profits to industrialists and more jobs than other plastic waste such as polyethylene, less economically attractive to recyclers and industrialists.

2. Methodology

This research is documentary and experimental, with a quantitative approach; the sources of information were secondary; the descriptive information collection technique based on the information found in scientific databases was used, once the documents and notes on the subject were found. The research is divided into three phases: First, information was collected from secondary sources such as scientific databases. Second, the recycled material was obtained and samples were manufactured. And third, laboratory tests and economic analysis were performed.

For the second phase, plastic that had been thrown as solid waste was recovered, as can be seen in Figure 1.

Figure 1
Collection from the Montebello Antioquia Municipality

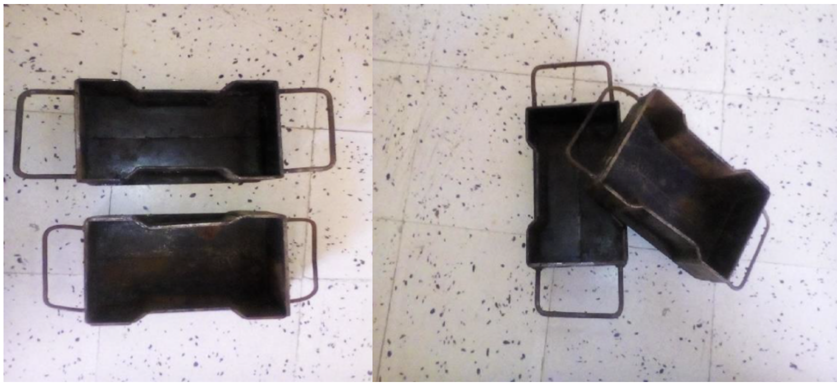
Source: authors

Afterwards, plastic was cut into small pieces, then melted and sand was added. Once it became manageable and homogeneous, the mixture was deposited in molds, allowed to cool, and then taken to the laboratory for analysis, as shown in Figures 2, 3 and 4.

Figure 2
Artisan process of recovered plastic

Source: authors

Figure 3
Fabricated metal molds



Source: authors

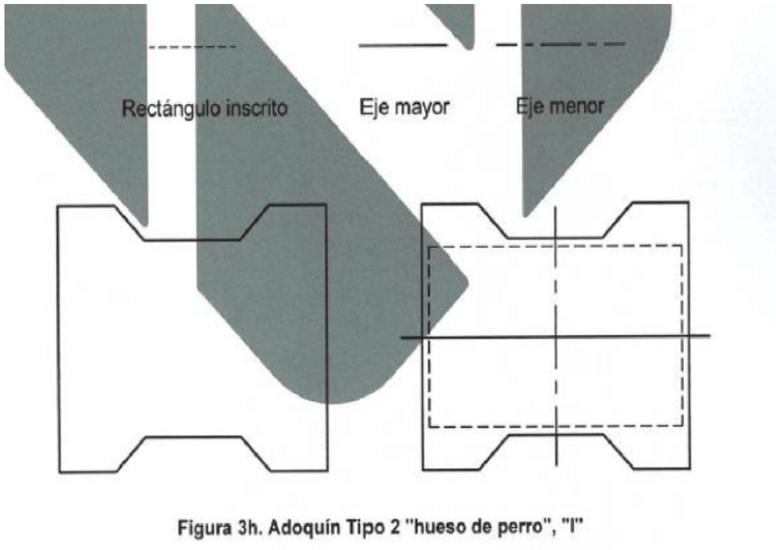
Figure 4
Paver made of recycled plastic

Source: authors

To manufacture a specimen, a considerable amount of discarded everyday items such as bags, plastic containers, vessels, furniture, toys, and many artefacts are required. In Colombia, according to the *Boletín Técnico Cuenta Ambiental* issued by the National Administrative Department of Statistics (DANE, 2016), approximately 35% of solid waste produced in the country is recovered for the production of new raw materials, with 1.9 million tons used.

For the third phase, the samples were tested taking into account the technical standard NTC (2017), which establishes the requirements for building concrete pavers for pedestrian, vehicular traffic, etc. The sample was manufactured with the figure for Paver Type 2, as shown in Figure 5.

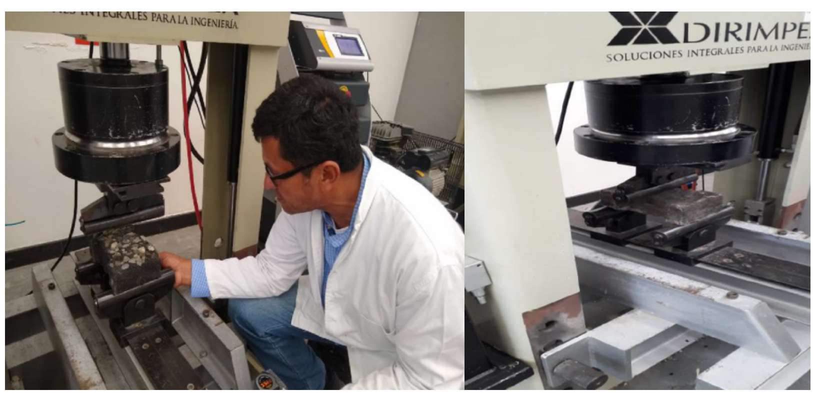
Figure 5
Sample to test, page 13 (ICONTEC, 2002).



According to the NTC 2017 standard, the mass according to 3.2.1., Is Mono Layer Paver. The mass consists of a single layer of material (recycled plastic and sand). The dimensions comply with the numerals: 4.1.1.1. (length less than 250 mm), 4.1.12 (width greater than 50 mm), and 4.1.1.3 (thickness greater than 60 mm).

The tests were carried out in the laboratory of the Cajicá campus of the Nueva Granada Military University, using the Universal Machine, as can be seen in Figure 6.

Figure 6
Universal Machine CVi TECH.



Source: authors.

3. Results

3.1. Flexo Traction Test (Flexion)

According to the NTC 2017, the Module of Rupture (Mr) must comply with what is indicated in Table 1: Flexural Strength Requirements (Mr), considering it is for concrete pavers:

Table 1
Taken from the NTC 2017 standard (ICONTEC, 2002)

Mr at 28 days in Megapascals (MPa)		**Print length (lh) Maximum in mm**
Average of 5 specimens	Individual	Average of 5 specimens
5	4.2	-
4.2	3.8	23

There is no standard that regulates the Flexotraction test for samples made from recycled plastic materials, to compare resistance with conventional pavers of hydraulic concrete. The test was performed on 4 of the object specimens (Table 2). There is no Colombian standard that regulates pavers made of recycled plastic, however, the Flexion test was carried out in compliance with the NTC 2017 standard, Section 4.4 Resistance to Flexural Traction, Module of Rupture (Mr). A total of 4 samples were tested, so dimensions were measured and recorded (Table 2).

Table 2
Dimensions of samples made from recycled material

SAMPLE	**INSCRIBED RECTANGLE**		
	LENGTH	**WIDTH**	**THICKNESS**
	mm	mm	mm
1	204	96	72.3
2	208.7	100	69.7
3	207.73	111	64.3
4	206.8	103,1	73.27

Source: authors

The test was carried out with the Universal Machine at a speed of 8 mm / min, obtaining the results shown in Table 3.

Table 3
Loads in KN for every 10 thousandths of an inch

UNITS	SAMPLE 1	SAMPLE 2	SAMPLE 3	SAMPLE 4
	50% Sand	50% Sand	50% Sand	50% Sand
	Load applied in KN			
10	1.75	1.98	1.84	2.45
20	2.95	2.6	1.93	2.86
30	4.3	3.48	2.1	3.14
40	5.23	4.35	2.36	3.55
50	6.6	5.3	2.42	4.35
60	8.1	6.4	2.75	5.13

UNITS	SAMPLE 1	SAMPLE 2	SAMPLE 3	SAMPLE 4
	50% Sand	50% Sand	50% Sand	50% Sand
	Load applied in KN			
70	9.6	7.61	2.88	5.98
80	10.32	9.21	3.04	7.02
90	13.67	10.82	3.53	8.16
100	16.48	12.61	4.2	9.52
110	19.9	14.7	4.85	10.2
120	23.41	16.72	5.56	12.35
130	26.48	18.56	6.25	13.54
140	20.15	20.94	7.23	14.83
150	32.63	22.96	8.25	16.15
160	34.45	25.96	9.32	17.36
170	32.25	26.88	10.3	19.96
180	22.21	28.5	11.46	17.25
190	16.14	30.01	12.52	16.02
200		31.58	13.68	13.98
210		32.63	14.76	
220		33.78	15.56	
230		34.76	16.22	
240		35.68	15.45	
250		36.07	13.86	
260		36.7		
270		36.77		

Source: authors

The specimens showed failure to the middle third, as shown in Figure 7. Thus, the Mr was calculated with equation 6.4.4.1. of the NTC 2017 standard, as observed in equation 1.

$$Mr = \frac{[3*Cmáx*(li-20)]}{[(ar+ai)*er^2]} \qquad (1)$$

Where “Mr” is the Module of Rupture, N/mm; “Cmáx”, maximum rupture load, in N; “li”, inscribed rectangle length in mm; “ar”, actual specimen width in mm; “ai”, inscribed rectangle width in mm; “er”, actual specimen thickness in mm. Based on equation 1, the Mr for each sample was determined:

Sample 1: Mr = $[3*34450*(204-20)]/[(2*96)*72.3^2]$ = 18.94 $(N/mm)^2$ = 18.94 Mpa

Sample 2: Mr = $[3*36770*(208.7-20)]/[(2*100)*69.7^2]$ = 21.42 $(N/mm)^2$ =21.42 Mpa

Sample 3: Mr = [3∗16220∗(207.73−20)]/[(2∗111)∗64.3^2] = 9.95 (N/mm)^2 = 9.95 Mpa

Sample 4: Mr = [3∗19960∗(206.80−20)]/[(2∗103.1)∗73,27^2] = 10.10 (N/mm)^2 = 10.10 Mpa

Figure 8
Failure to the middle third of the specimen

Source: authors

Consequently, the maximum deformation before rupture was obtained as follows:

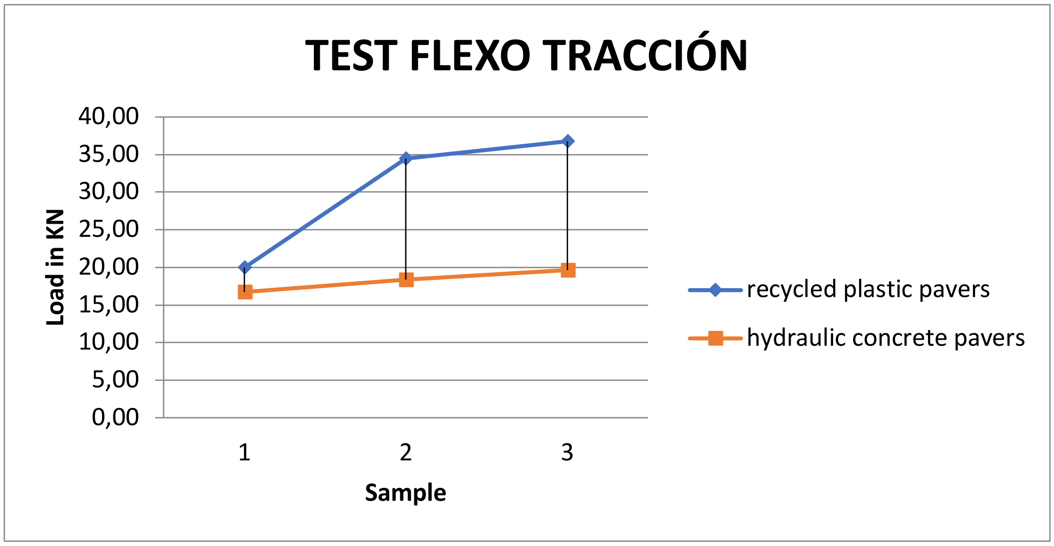
Sample 1: 160 und * 0.001* 0.0254 * 1000 = 4.06 mm.

Sample 2: 270 und * 0.001* 0.0254 * 1000 = 6.858 mm.

Sample 3: 230 und * 0.001* 0.0254 * 1000 = 5.842 mm.

Sample 4: 170 und * 0.001* 0.0254 * 1000 = 4.318 mm.

Figure 9
Comparison of applied loads in the flexotraction trial



Source: author[3]

[3] The blue line represents the recycled plastic pavers while the orange line represents the hydraulic concrete pavers.

Figure 9 shows the comparison of the maximum loads applied for both pavers with recycled plastic and hydraulic concrete pavers. For the samples of hydraulic concrete, Mr results were made in a particular laboratory (Figure 10).

Figure 10
Mr results for hydraulic concrete pavers

CONCRETE PAVERS									
FLEXOTRACTION RESISTANCE (Mr)									
NTC 2017 STANDARD									
PAVER No.	Description	Trial date	DIMENSIONS				Rupture load in KN	Mr	
			Length of the major axis of the inscribed rectangle (mm)	Length of the minor axis of the inscribed rectangle B (mm)	Distance between support axes L (mm)	Paver thickness B (mm)		MPa	kg/cm^2
1	Vehicular paver	06/11/2019	200.00	100.00	180,00	80.00	16.72	7.10	70.50
2		06/11/2019	200.00	100.00	180.00	80.00	19.64	8.30	82.90
3		06/11/2019	200.00	100.00	180.00	80.00	18.33	7.70	77.30
AVERAGE:								7.70	76.90

Source: authors

According to results obtained, after testing three pavers of hydraulic concrete, the most used for the construction of vehicular roads, it can be seen that the Mr of pavers made of recycled plastic material is greater than for those manufactured with hydraulic concrete.

3.2 Compression trial

The dimensions of the samples for compression testing, in total, were three manufactured with recovered polymer and a sample with hydraulic concrete, as can be seen in Table 4.

Table 4
Specimen dimensions

Compression trial				
Sample	**Inscribed rectangle**			
	Length	Width	Thickness	Area
	mm	mm	mm	cm2
1	208	100.5	66	20.904
2	206.3	107.5	64.3	22.17725
3	206	107.5	58	22.145
Concrete sample	201.53	100.48	80.81	20.24973

Fuente: autores

Applied loads: Sample 1: 210 KN; Sample 2: 400 KN; Sample 3: 460 KN; Concrete sample: 340 KN.

Obtained compression resistance:

Sample 1: 210000 N / 20904 mm² = 10,0406 Mpa

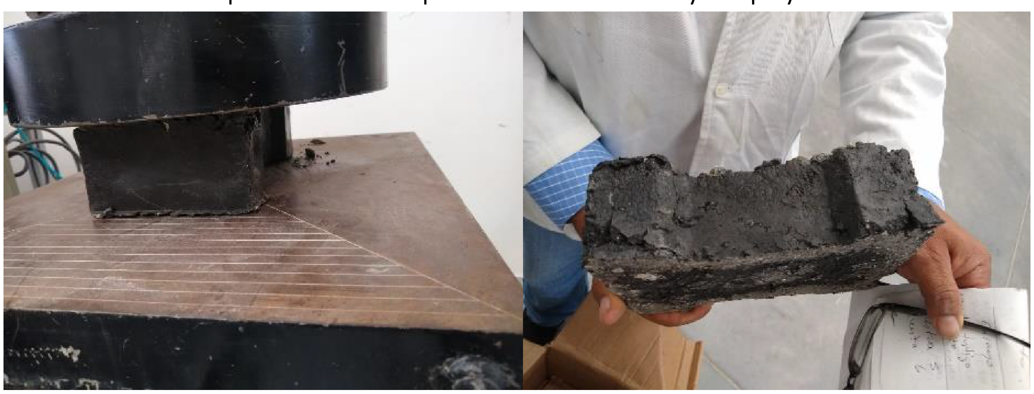
Sample 2: 400000 N / 22177 mm² = 18,037 Mpa

Sample 3: 460000 N / 22145 mm² = 20,772 Mpa

Concrete sample: 340000 N / 20249 mm² = 16,79 Mpa

According to the previous calculations, it can be concluded that specimens manufactured with recycled polymers (samples 2 and 3) showed a greater load capacity than the sample manufactured with hydraulic concrete. The behavior of the samples manufactured with plastic materials recovered according to what was observed, specifically sample 3, could withstand the maximum load of the universal testing machine which is 460 KN max. Samples 2 and 3 did not suffer rupture, but bulging was observed on their lateral faces (Figures 11 and 12).

Figure 11
Compression trial for specimens made with recycled polymers



Source: authors

Figure 12
Compression trial for concrete specimen

Source: authors

3.3. Temperature resistance

In order to verify high temperature resistance, two samples were chosen, which were subjected to 100°C in the oven for eight hours. Specimens did not show deformation or softening, therefore, it is concluded that pavers made of recycled plastic resist high temperatures considering that the maximum temperature in Colombia does not exceed 46°C. More comprehensive and rigorous studies should be made that allow for more precise and reliable knowledge about this variable.

3.4. Water absorption

The samples in total 2 were submerged in water as required by the NTC 2017 standard in section 4.3. The specimens were weighed completely dry on the electronic scale with the following absorption percentages: 0.087% for sample 1, and 0.095% for sample 2. According to the aforementioned standard, the absorption percentage should not be greater than 7% for concrete pavers. As the samples are made of recycled plastic and sand, these pavers show excellent results for this variable.

3.5. Economic comparison

Table 5
Economic comparison for hydraulic concrete and recycled plastic pavers

Manual manufacture					**Manual manufacture**				
210 kg/cm2 concrete pavers					**248 Kg/cm2 recycled plastic pavers**				
Type of material	Price in cop	Units	Amount of pavers	Unit price in cop	Type of material	Price in cop	Units	Amount of pavers	Unit price in cop
Sand	43000	m3	915	47	Sand	43000	m3	915	47
Cement	23030	bulto	130	177	Polymer	300	Kg	1	300
Water	800	m3	411	1.95	Workforce	5800	m2	44	132
Workforce	5800	m2	44	132					
Production cost for each paver =				358	Production cost for each paver =				479
sale property =				1300	sale property =				1300
utility =				942	utility =				821

Source: authors

According to the values obtained and reflected in Table 5, production costs for pavers made of recovered plastic materials (high and low density polymers) are 33.8% higher than for those made of hydraulic concrete. Despite higher production cost, the utility of recovered plastic pavers may be greater because concrete pavers have a maturity time of 28 days as required by the NTC 2017 Standard, while recycled polymers can be installed within 24 hours of its manufacture. Approximately 560 kilograms per day can be compressed with a crusher to process recycled plastic. Using an extruder to melt and mix the plastic with the sand, up to 900 pavers can be manufactured per day. Plastic crushers can be obtained at a commercial price of 10 million pesos, while the national manufacturing extruder has an estimated cost of 120 million pesos, according to a quote made to the company Ecomadera in the city of Bogotá.

4. Discussion and conclusions

Plastic materials have become a pollutant that causes concern to the environmental authorities and society in general. According to data provided by Dinero.Com magazine (June 17, 2018) approximately 12 million tons of garbage are produced in Colombia per year, and only 17% is recycled, of which plastic is the least recovered (www.dinero.com/edicion-impresa/pais/articulo/cuanta-basura-genera-colombia and-how-much-recycle/249270)

To exemplify the manufacture of pavers with recycled material, if five kilometers of tertiary roads or Veredales[4] with an average width of five meters had to be paved, 1,100 tons would be used, representing only 6% of the national annual production; on platforms or pedestrian paths per 100 linear meters, 6.6 tons would be used for 150 square meters. As can be evidenced, the use of this raw material would generate a great benefit for the environment, as well as several direct and indirect jobs.

The literature reviewed evidences the lack of technical standards. In Colombia, the technical standard NTC 2017 on concrete pavers regulates the manufacture of hydraulic concrete pavers. However, there are no specific standards for the implementation, manufacturing and installation of pavers made from recovered materials as an alternative material, such as recycled plastic for the construction of vehicular roads and pedestrian paths.

The production costs for recovered polymer pavers are very economically favorable for their manufacture and commercialization. Manufacturing a hydraulic concrete paver has a cost that ranges between 358 and 450 Colombian pesos, while manufacturing a paver with recycled plastic and sand costs 479 and 500 Colombian pesos. Yet, when considering the optimal curing time, it takes 28 days to deliver hydraulic concrete pavers, according to the NTC 2017 standard, while recycled plastic pavers can be used once it is completely cold, which is about 24 hours. This means that while the latter is more expensive, the waiting times are more reasonable. Although the production cost for plastic pavers is 10% higher; environmental benefits must also be taken into account: reusing waste such as plastic will reduce the environmental impact of this material, which is currently not a biodegradable material, and is hazardous for health and the environment. With this use, a new application becomes possible.

The resistance of recycled polymer pavers, according to trial results, allows to conclude that they are efficient from a technical and economic point of view, and that they can be used in the construction, repair and habilitation of vehicular roads in urban and rural areas. According to flex results, the load plastic pavers could support before rupture is up to 53% higher than concrete pavers, with a maximum load of 36.77 kN, whereas hydraulic concrete pavers have a maximum load of 19.64 kN. In the compression test, pavers made of hydraulic concrete support a load of 340 kN, while pavers with recycled material support a load up to 460 kN, which is the maximum value recorded by the universal machine used. Recycled plastic pavers supported more load before rupture and their bending is greater, 4 mm on average, while those of hydraulic concrete are close to 2 mm. Thus, this could be a very good economic and efficient option to use in parking lots, urban roads and pedestrian paths.

As possible future lines of research, studies could be extended to paving stones with recyclable material to verify resistance to chemical agents such as acids, solvents, salts, oxidants, among others. From an economic point of view, its possible development and commercialization in other cities of Colombia and Latin America could be analyzed, where this type of material is a viable alternative from a technical, environmental and economic point of view.

[4] The *Zonas Veredales Transitorias de Normalización (ZVTN)* (Transitional Normalization Zones) and the *Puntos Transitorios de Normalización (PTN)* (Transitional Normalization Points) are areas of temporary location until the culmination of the disarmament process in Colombia.

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Bibliographic references

ALESMAR, L., RENDON, N., & KORODY, M. E. (2008). Mezclas de cemento y agregados de plastico para la construccion de viviendas ecologicas. *Rev. Fac. Ing. UCV [online], 23*(1), 76-86. Disponible en: <http://ve.scielo.org/scielo.php?script=sci_arttext&pid=S0798-40652008000100006&lng=es&nrm=iso>.

Álvarez, D., & Calderón, Y. (2001). *Estudio Comparativo del comportamiento del concreto simple y del concreto reforzado con fibra de polipropileno.* Trabajo de grado, Universidad Industrial de Santander, Bucaramanga. Disponible en "https://upcommons.upc.edu/bitstream/handle/2099.1/6554/01.pdf?sequence=2".

ALZATE RODRÍGUEZ, S., & TAFUR RUGE, F. (2006. Disponible en: "http://repository.lasalle.edu.co/bitstream/handle/10185/14773/00798198.pdf?sequence=1"). *FACTIBIL IDAD EC ONÓMICA, AMBIENTAL Y S OCIAL DEL PR OC ESO D E FABRICACIÓN DE ADOQUINES CPM DE FLEXIFORM COMO ALTERNATIVA PARA LA FORMACIÓN DE R ECUPERADOR ES DE BOGOTÁ D.C.* Trabajo de grado, Universidad de La Salle, Bogotá.

Brunoticias. (Marzo de 2018). Obtenido de Brunoticias: https://www.brunoticias.com/crean-adoquines-plastico-pet-reciclado/

Cabo Laguna, M. (2011). *Ladrillo ecológico como material sostenible para la construcción.* Tesis de Grado, Escuela Técnica Superior De Ingenieros Agrónomos, Pamplona, España.

Constantin, J., Shitote, S., Abiero Gariy, Z., & Ronoh, E. (2019). Influence of coarse aggregate on the physical and mechanical performance of paving blocks made using waste plastic. *International Journal of Engineering Research and Technology*, Volume 12, Issue 6, Pages 912-916. Available at: https://www.ijert.org/research/influence-of-coarse-aggregate-on-the-physical-and-mechanical-performance-of-paving-blocks-made-using-waste-plastic-IJERTV8IS060171.pdf.

Departamento Administrativo Nacional De Estadística. (2016). Obtenido de Boletín técnico Cuenta Ambiental y Económica de Flujo de Materiales – Residuos Sólidos: https://www.dane.gov.co/files/investigaciones/pib/ambientales/cuentas_ambientales/cuentas-residuos/Bt-Cuenta-residuos-2016p.pdf

Di Marco Morales, R. O., León Téllez, H. A., & Almeira, J. E. (diciembre de 2016). Diseño y elaboración de ladrillos con adición de pet (material reciclado), para núcleos rurales del socorro . *El Centauro, 8*(11), Disponible en: <https://doi.org/10.18041/2027-1212/centauro.11.2016.2448>.

Di Marco, R. (2014). Diseño y elaboración de un sistema de adoquines de bajo costo y material reciclado para construcciones en núcleos rurales. *Revista Esaica, I*(I), 47-57.

Emmanuel, E., Perrodin, Y., Keck, G., Blanchard, J., & Vermande, P. (2005). Ecotoxicological risk assessment of hospital wastewater: a proposed framework for raw effluents discharging into urban sewer network. *Journal of Hazardous Materials*, Volume 117, Issue 1. pp. 1-11. Available at: https://doi.org/10.1016/j.jhazmat.2004.08.032.

Enka De Colombia S.A. (2015). Obtenido de ENKA DE COLOMBIA S.A.: http://www.enka.com.co/enka/

Flores, V., Rojas, J., Torres, R., Vallejos, R., Flores, P., & M., F. (2014). Mezclas de cemento y agregados de plastico para la construccion de viviendas ecologicas. En R. y. Universidad Mayor, *Ciencias Tecnológicas y Agrarias T-I* (págs. 101-110). México, México: ECORFAN-México.

Guerrero, K. (2015). Obtenido de Adoquines en base de materiales reciclables: http://adoquinenbaseamaterialreciclado.blogspot.com/2015/06/

Halden, R. (2010). Plastics and Health Risks. *Annual Review of Public Health*, Vol. 31, pp.179-194. Available at: https://doi.org/10.1146/annurev.publhealth.012809.103714.

ICONTEC. (2002). Obtenido de Norma técnica colombiana NTC 2017 : adoquines de concreto para pavimentos / ICONTEC: https://www.icontec.org/

Pastor Castillo, A., Salazar Oliva, J. P., Seminario Regalado, R., Tineo Camacho, A., & Zapata Valladolid, J. C. (noviembre de 2015). Obtenido de Universidad de Piura: https://pirhua.udep.edu.pe/bitstream/handle/11042/2343/5.%20PYT%2C%20Informe%20Final%2C%20Cemento%20y%20Pl%C3%A1stico.pdf?sequence=1&isAllowed=y

PIÑEROS MORENO, M. E., & HERRERA MURIEL, R. D. (Noviembre de 2018). Obtenido de PROYECTO DE FACTIBILIDAD ECONÓMICA PARA LA FABRICACIÓN DE BLOQUES CON AGREGADOS DE PLÁSTICO RECICLADO (PET), APLICADOS EN LA CONSTRUCCIÓN DE VIVIENDA: https://repository.ucatolica.edu.co/bitstream/10983/22382/1/TESIS%20BLOQUE%20PET.pdf

Reddy, C., Chandra Kumar, B., & Asadi, S. (2019). Utilization of low density polyethylene waste in the manufacturing of paver brick. *International Journal of Recent Technology and Engineering*, Volume 7, Issue 6C2, pp 62-67. Available at: https://www.ijrte.org/wp-content/uploads/papers/v7i6c2/F10120476C219.pdf.

Serrano-Guzman, M., & Perez-Ruiz, D. (2011). Use of Recycled Materials to Build Paver Blocks for Low-Volume Roads in Developing Countries. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2205, Issue 1. Available at: https://doi-org.ezproxy.umng.edu.co/10.3141%2F2205-18.

Sierra Jiménez, J. A. (2016). *Usos y aplicaciones del plástico PEADreciclado en la fabricación de elementos estructurales para construcción de viviendaen Colombia.* Trabajo de grado de Magister en Ingeniería Civil, Escuela Colombiana de IngenieríaJulio Garavito, Bogotá.

Tulashie, S., Boadu, E., Kotoka, F., & M. D. (2020). Plastic wastes to pavement blocks: A significant alternative way to reducing plastic wastes generation and accumulation in Ghana. *Construction and Building Materials*, Vol. 241, Article number 118044. Available at: https://doi-org.ezproxy.umng.edu.co/10.1016/j.conbuildmat.2020.118044.

Van, V., Rößler, C., & Bui, D. (2014). Pozzolanic reactivity of mesoporous amorphous rice husk ash in portlandite solution. *Construction and Building Materials*, Volume 59, Pages 111-119. Available at: https://doi.org/10.1016/j.conbuildmat.2014.02.046.