Ingeniería Solidaria

Analysis of the flexural behavior of pavers made from recycled plastic; with a combination of high-density polyethylene (HLPE), low-density polyethylene (LDPE)and polypropylene (PP)

Análisis del comportamiento a flexotracción de adoquines elaborados a partir de plástico reciclado; con combinación de polietileno de alta densidad (HLPE), polietileno de baja densidad (LDPE) y polipropileno (PP)

Análise do comportamento à flexão de pavimentos feitos de plástico reciclado; com uma combinação de polietileno de alta densidade (HLPE), polietileno de baixa densidade (LDPE) e polipropileno (PP)

Alfonso Giraldo Toro[1]
Nayive Nieves Pimiento[2]
Luini Leonardo Hurtado Cortés[3]

Received: November 20th, 2024
Accepted: March 4th, 2024
Available: May 7th, 2024

How to cite this article:
A. Giraldo Toro, N. Nieves Pimiento, L.L. Hurtado Cortés, "Analysis of the flexural behavior of pavers made from recycled plastic; with a combination of high-density polyethylene (HLPE), low-density polyethylene (LDPE) and polypropylene (PP)," *Revista Ingeniería Solidaria*, vol. 20, no. 2, 2024.
doi: https://doi.org/10.16925/2357-6014.2024.02.01

Research article. https://doi.org/10.16925/2357-6014.2024.02.01

1 Mechanical Technology Student. Faculty of Technology, Mechanical Technology, Universidad Distrital Francisco Jose de Caldas, Bogota, Colombia
Email: agiraldot@udistrital.edu.co
ORCID: https://orcid.org/0000-0003-3912-5532
CvLAC: https://scienti.minciencias.gov.co/cvlac/EnRecursoHumano/inicio.do

2 Master in Environmental Sciences, Mechanical Engineering. Faculty of Engineering, Environmental Engineering, Reseach Group environmental management and sustainable development, Universidad ECCI, Bogota, Colombia
Email: nnievesp@ecci.edu.co
ORCID: https://orcid.org/0000-0003-2914-4836
CvLAC: https://scienti.minciencias.gov.co/cvlac/visualizador/generarCurriculoCv.do?cod_rh=0001567751

3 Ph.D. in Engineering - Automatic, Master in engineering - Industrial Automation, Mechanical Engineering. Faculty of Technology, Mechanical Engineering, Universidad Distrital Francisco Jose de Caldas, Bogota, Colombia
Email: llhurtadoc@udistrital.edu.co
ORCID: https://orcid.org/0000-0002-1675-9471
CvLAC: https://scienti.minciencias.gov.co/cvlac/visualizador/generarCurriculoCv.do?cod_rh=0000783960

Abstract

Introduction: This paper entails an analysis of flexural behavior of pavers made from recycled plastic; a combination of high-density polyethylene (HLPE), low-density polyethylene (LDPE) and polypropylene (PP), carried out in the period 2022 to 2023, with the academic support of the Universidad Distrital Francisco José de Caldas, Sede Tecnológica; Bogotá - Colombia.

Problem: To perform flexural tests and analyze the behavior of pavers made from recycled plastic.

Objective: To calculate the Flexural Strength (Re), Maximum Stress, Maximum Breaking Load (Cmax), Modulus of Rupture (Mr), Young's Modulus, for a sample of 15 paving blocks made from HLPE, LDPE, PP and compare with the NTC 2017 standard.

Methodology: 15 flexural tests were performed on the specimens selected for the study, and calculations were made for their respective analysis.

Results: For flexural strength, the NTC 2017 standard establishes ranges of 3.8 to 4.2 MPa for individual tests and 4.2 to 5 in grouped tests; for the study carried out, a range of 10.8965 ≤ flexural strength (MPa) ≤ 13.5987 was found.

Conclusion: Tests indicate that recycled plastic pavers have a higher modulus of rupture than conventional pavers.

Originality: Due to the lack of existing information on the subject of paving stones, it is original to carry out a study of paving stone flexural strength and to evaluate the behavior compared to the standard.

Limitations: Did not perform electron microscopy analysis on the material.

Keywords: high-density polyethylene, low-density polyethylene, polypropylene (PP), specimens, strength, rupture, particle.

Resumen

Introducción: El proyecto de análisis del comportamiento a flexotracción de adoquines elaborados a partir de plástico reciclado; con combinación de polietileno de alta densidad (HLPE), polietileno de baja densidad (LDPE) y polipropileno (PP), realizada en el periodo 2022 a 20231, con el apoyo académico de la Universidad Distrital Francisco José de Caldas, Sede Tecnológica; Bogotá – Colombia.

Problema: Analizar bajo los ensayos de flexotraccion el comportamiento de los adoquines elaborados a partir de plástico reciclado.

Objetivo: El proyecto de investigación es calcular la Resistencia a la flexotración (Re), Esfuerzo Maximo, Carga máxima de rotura (Cmax), Modulo Rotura (Mr), Modulo de Young, para una muestra de 15 adoquines elaborados a partir de HLPE, LDPE, PP y comparar con la norma NTC 2017.

Metodología: Se realizaron 15 ensayos a flexotracción de las probetas seleccionadas para el estudio, se realizaron los cálculos para su respectivo análisis.

Resultados: Para resistencia a la flexotracción la norma NTC 2017, establece rangos de 3.8 a 4.2 Mpa por pruebas individuales y 4.2 a 5 en pruebas agrupadas, para el estudio realizado se encontró en un rango 10.8965 ≤ flexotracción (MPa) ≤ 13.5987.

Conclusión: Las pruebas indican que los adoquines de plástico reciclado tienen un módulo de ruptura superior al de los adoquines convencionales.

Originalidad: Por la poca información existentes en el tema de adoquines pasticos, es original realizar un estudio de flexotraccion de adoquines y evaluar en comportamiento comparado con la norma.

Limitaciones: No realizar un análisis de microscopia electrónica en el material.

Palabras clave: Polietileno de alta densidad, polietileno de baja densidad, polipropileno (PP), probetas, resistencia, rotura, partícula.

Resumo

Introdução: O projeto de análise do comportamento à flexão de pavimentos feitos de plástico reciclado; com combinação de polietileno de alta densidade (PEHL), polietileno de baixa densidade (PEBD) e polipropileno (PP), realizado no período de 2022 a 20231, com apoio acadêmico da Universidade Distrital Francisco José de Caldas, Sede Tecnológica; Bogotá – Colômbia.

Problema: Analisar o comportamento de pavimentos feitos de plástico reciclado em testes de flexotração.

Objetivo: O projeto de pesquisa consiste em calcular a Resistência à Flexão (Re), Tensão Máxima, Carga Máxima de Ruptura (Cmax), Módulo de Ruptura (Mr), Módulo de Young, para uma amostra de 15 pavimentadoras feitas de HLPE, LDPE, PP e comparar com o padrão NTC 2017.

Metodologia: Foram realizados 15 ensaios de flexão nos corpos de prova selecionados para o estudo, foram realizados os cálculos para suas respectivas análises.

Resultados: Para resistência à flexão, a norma NTC 2017 estabelece faixas de 3,8 a 4,2 Mpa para testes individuais e de 4,2 a 5 em testes de grupo. Para o estudo realizado, foi encontrada faixa de 10,8965 ≤ flexão (MPa) ≤ 13,5987.

Conclusão: Os testes indicam que as pavimentadoras de plástico reciclado apresentam um módulo de ruptura mais elevado do que as pavimentadoras convencionais.

Originalidade: Devido à pouca informação disponível sobre o tema das pavimentadoras plásticas, é original realizar um estudo de flexotração das pavimentadoras e avaliar o seu comportamento em relação à norma.

Limitações: Não realize análises de microscopia eletrônica no material.

Palavras-chave: Polietileno de alta densidade, polietileno de baixa densidade, polipropileno (PP), tubos de ensaio, resistência, quebra, partícula.

1. INTRODUCTION

The large-scale production of easily disposable materials and excessive human consumption have led to serious environmental problems worldwide. The inadequate disposal of these materials has generated a large amount of waste that pollutes the environment, affecting human health and the biodiversity of ecosystems; this waste is disposed of in natural resource sources such as rivers, seas and soils, which further aggravates the situation. The environmental impact of waste is very high and can affect the quality of air, water and soil, endangering human health and the survival of animal and plant species. Waste production can be reduced and the circular economy promoted by reusing, repairing and recycling materials to prolong their useful life and reduce their environmental impact [1].

Plastic is one of the most widely used materials in everyday life and in different fields of human activities. However, most of the plastics produced are single-use plastics and this generates a disproportionate production of waste. About 86% of plastic packaging is used only once before being discarded, which increases the amount of plastic waste generated and its impact on the environment; this waste ends up in landfills, rivers and seas, endangering life innature [2].

Plastics for containers and packaging are non-biodegradable; they cannot be brokendown by biological organisms. This is because they are designed to be tough and durable, which makes them useful in many applications, but also makes them difficult to handle and dispose of; this resistance to microbial attack makes the collection and disposal of plastic waste even more difficult [3].

In Colombia, only 17% of all solid waste, including plastics, is recycled. This shows the need to develop effective policies and strategies for the proper management of waste and to promote the circular economy, in which materials are reused and recycled to prolongtheir useful life and reduce their environmental impact. In order to achieve a more efficient waste management, it is necessary to involve all actors of society, including citizens, companies, governments and social organizations; implementing education and awareness campaigns on the importance of proper waste management and recycling, as well as developing infrastructure and systems for waste collection, transportation and treatment that maximize the use of materials and minimize their environmental impact [4].

In recent years the use of recycled materials in engineering has become a potential for reducing waste and promoting sustainability. In particular, recycled plastic which has been the subject of research for use in a wide variety of applications, including the manufactureof engineering products [5].

From research and innovation, testing techniques have been developed to characterize and evaluate the mechanical, thermal and chemical properties of recycled materials, particularly high-density polyethylene (HDPE), low-density polyethylene (LDPE) and polypropylene (PP), which is essential to ensure that they are suitable for use in specific applications. This includes the development of tensile, flexural, compression and other tests to measure the strength and stiffness of recycled materials [6], [7].

The research presented refers to the analysis of the flexural behavior of pavers made from recycled plastic; with a combination of high-density polyethylene (HLPE), low-density polyethylene (LDPE) and polypropylene (PP), evaluating the mechanical properties ofthe material, to determine the quality and resistance of the pavers made from recycled plastic and compare them with the standards of the construction industry. Flexural strength tests are performed under the Colombian Technical Standard NTC-2017 [8], evaluating and determining the suitability of the pavers for use in construction applications.

1.1 Literature review or research background

Recycled plastic materials have gained popularity in the construction industry because of their potential to reduce dependence on natural resources and minimize waste. In particular, pavers made from recycled plastic have been the subject of research and development for use in sustainable paving applications. This literature review focuses on the analysis of the flexural behavior of pavers made from a combination of high-density polyethylene (HLPE), low-density polyethylene (LDPE) and polypropylene (PP).

One of the key aspects to consider in the manufacture of pavers from recycled plastic is their ability to resist cyclic loading and deformation due to vehicular and pedestrian traffic. Several studies have addressed this issue and investigated the mechanical properties of recycledplastic pavers.

In a study by Smith et al. [9], the influence of the mixing ratio between HLPE, LDPE and PP on the flexural strength of pavers was evaluated. The results showed that higher HLPE content led to higher flexural strength, whereas an increase in LDPE and PP content resulted in a decrease in strength. These findings indicate the importance of optimizing material composition to achieve optimum performance in terms of flexural shrinkage.

On the other hand, Johnson et al. [10] conducted a comparative study between pavers made entirely of recycled plastic and conventional concrete pavers. They found that recycled plastic pavers exhibited flexural strength comparable to that of concrete pavers, suggesting their viability as an environmentally friendly and sustainable alternative.

The addition of additives and reinforcements has also been investigated inthe improvement of the mechanical properties of recycled plastic pavers. A study by Li et al. [11] investigated the effect of the incorporation of reinforcement fibers on the flexural strength of pavers. It was observed that the addition of polypropylene significantly improved the flexural strength and reduced the plastic deformation of the pavers.

Existing literature indicates that pavers made from recycled plastic have promising potential as a sustainable alternative to conventional pavers made from non-recycled materials. Proper selection of the mix components, together with optimization of the proportions of high-density polyethylene (HLPE), low-density polyethylene

(LDPE) and polypropylene(PP), play a crucial role in the flexural strength of the pavers. In addition, it has beenshown that the addition of additives and reinforcements, such as polypropylene fibro, can further improve the mechanical properties of recycled plastic pavers.

In addition to the studies mentioned above, research has been carried out on other relevant aspects in the analysis of the flexural behavior of pavers made from recycled plastic. For example, the influence of different processing techniques on the mechanical properties of the pavers has been studied.

In a study by Chen et al. [12], pavers manufactured by extrusion and injection molding processes were compared. It was found that the pavers produced by injection molding exhibited higher flexural strength compared to those manufactured by extrusion. Thiswas attributed to better molecular orientation and higher density in the injection molded pavers.

The incorporation of mineral fillers and other reinforcing materials has also been investigated. For example, a study by Wang et al. [13] investigated the effect of the addition of glass fibers in recycled plastic pavers. It was observed that the presence of glassfibers significantly improved the flexural strength and toughness of the pavers, providing higher load-bearing capacity and deformation resistance.

A study by Garcia et al. [14] investigated the effect of incorporating natural fibers, such ascoconut fibers, into recycled plastic pavers. The results showed that the addition of coconut fibers improved the flexural and flexural strength of recycled plastic pavers, suggesting its potential as a sustainable alternative to improve the mechanical properties of recycled plastic pavers.

A study by Wang et al. [15] investigated the effect of the addition of vegetable oil-basedplasticizers in recycled plastic pavers. The results showed that the incorporation of plasticizers improved the flexibility of the pavers and increased their flexural strength.

In terms of the durability and weatherability of recycled plastic pavers, studies have been conducted to evaluate their performance under different environmental conditions. A study by Lopez et al. [16] investigated the flexural strength of recycled plastic pavers aftersubjecting them to freeze-thaw cycles. The results showed that the pavers maintainedtheir flexural strength after freeze-thaw cycles, indicating their ability to withstand adverse climatic conditions.

In addition to the mechanical aspects, attention has also been paid to the sustainability and environmental impact of recycled plastic pavers. A study by Morales et al. [17] evaluated the life cycle of recycled plastic pavers and compared their environmental impact with conventional pavers made of non-recycled materials. The results indicated that recycled plastic pavers had a lower environmental footprint in terms of energy consumption and greenhouse gas emissions compared to conventional pavers.

The incorporation of additives and reinforcements, such as natural fibers and plasticizers, can improve the mechanical and physical properties of recycled plastic pavers. Additionally, research has been conducted on the durability, weatherability and environmental impact of these pavers. However, more research is needed to explore other additives and reinforcements, as well as to evaluate their long-term impact and performance indifferent environmental conditions.

The influence of the geometry and structure of recycled plastic pavers on their flexural behavior has also been investigated. A study by Zhang et al. [18] examined the effect of the size and shape of the recycled plastic pavers on their flexuralbehavior. It was found that pavers with more regular shapes and uniform sizes exhibited higher strength and structural stability.

In terms of regulations and standards, work has been done to develop guidelines and specifications for the manufacture and use of recycled plastic pavers. For example,ASTM D7889 [19] provides guidelines for the manufacture of recycled plastic paversand establishes minimum requirements for flexural strength.

In addition, comparative studies have been carried out between recycled plastic pavers and traditional materials such as concrete and asphalt. A study by Li et al. [20] evaluated the flexural performance of recycled plastic pavers in comparison with concrete pavers. The results showed that recycled plastic pavers exhibited comparable and even superior flexural strength in some cases, indicating their viability as a sustainablealternative in surface paving.

In terms of the durability of recycled plastic pavers, their resistance to aging and degradationunder environmental conditions has been investigated. A study by Zhang et al. [21] evaluated the flexural strength of recycled plastic pavers after repeated cycles of acceleratedaging. The results showed that, although there was a slight decrease in flexural strength, the pavers retained their structural integrity and maintained adequate performance.

However, despite advances in research on recycled plastic pavers, there are areas that require further exploration. For example, there is a need to investigate the long-term durabilityof these pavers under different environmental and climatic conditions. In addition, further studies are required to understand the effect of other factors, such as the size andshape of the pavers, on their flexural behavior [22].

In conclusion, the manufacture of pavers from recycled plastic, by combining high-density polyethylene (HLPE), low-density polyethylene (LDPE) and polypropylene

(PP), has been the subject of research in terms of its performance in terms of the recyclability of the pavers.

Existing studies indicate the importance of optimizing material composition and making use of additives and composites to improvethe mechanical properties of the pavers. However, additional research is required to address aspects such as long-term durability and the effect of other factors on the behavior of these pavers.

2. PROCEDURE AND METHODOLOGY

2.1. MATERIAL AND EQUIPMENT

2.1.1 Selection of pavers

Dimensions and weight Pavers

Weight = 1.4 kg (range of variation between 0.5 kg and 1.0 kg approximately).Length = 31.0 cm, width = 14.5 cm and thickness = 4.8 cm.

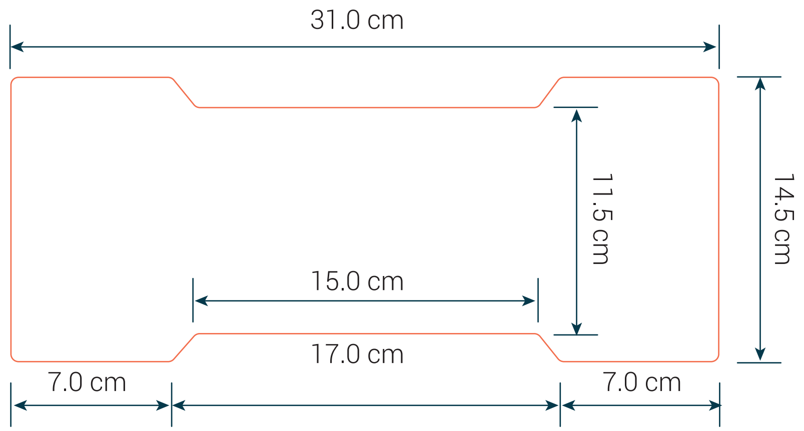

Figure. 1 Paver dimensions
Source: Own work

2.1.2 Sample Paving Stones

The pavers were selected based on the requirements established by the NTC 2017 Standard, flexural strength or modulus of rupture [8-10].

Fifteen specimens (pavers) were selected for the average tests and five specimens for the individual tests.

2.1.3 Experimental design

For flexural testing of the plastic pavers, the pavers were divided into two groups of 5 and 5 were selected for individual tests. Tables 1 and 2 present the specimens used for the test. The tests were carried out at the laboratory of the Universidad Distrital Francisco José de Caldas, technological headquarters in Bogotá, Colombia.

Table 1. Notation for specimens in average tests

FLEXOTRACTION TEST	SPECIMENS			
	#	**Notation**	**#**	**Notation**
Modulus of rupture average tests (NTC-2017)	1	ADQ - 1	6	ADQ - 6
	2	ADQ - 2	7	ADQ - 7
	3	ADQ - 3	8	ADQ - 8
	4	ADQ - 4	9	ADQ - 9
	5	ADQ - 5	10	ADQ - 10

Source: Authors.

Table 2. Notation for specimens in single tests

FLEXOTRACTION TEST	SPECIMENS	
	#	**Notation**
Modulus of rupture individual tests (NTC-2017)	11	ADQ - 11
	12	ADQ - 12
	13	ADQ - 13
	14	ADQ - 14
	15	ADQ - 15

Source: Own work

2.1.4 Equipment and testing

The flexural tensile test was performed to evaluate the stiffness and strength of the pavers under bending loads [23]. The specimens were subjected to a controlled bending load using the universal testing machine. The loads were applied at the center of the material specimen, while the ends are supported at fixed support points. The tests were performed onspecimens of the same dimensions and weights, subjecting them to bending loads up to the breaking point (Figure 1).

Figure 2. Flexural - tensile tests
Source: Own work

The 9 specimens were subjected to bending tests in the Universal Testing Machine (REF. UH 50-A Shimatzu). The arrangement of each specimen in the machine is shown in Figure 2.

Figure 3. Specimen arrangement (flexo-tensile)
Source: Own work

2.1.5 Data collection

The data were obtained with the standards and procedures established by the NTC 2017 standard [8], under the procedures and protocols of the Material Strength laboratory of the Universidad Distrital Francisco José de Caldas Bogotá, Colombia.

3. Results and Discussion

Tables 3 to 6 present the data obtained from the flexural tensile test following the guidelines of the Colombian technical standard 2017, for tests grouped in 5 specimens ADQ 1 to 5 (Table 3) and ADQ 6 to 10 (Table 5).

Table 3. Maximum Stress, Maximum Load, Modulus of Rupture ADQ1-5

Specimens	Flexural Strength		Maximum stress E vs D curve		Maximum breaking load		Modulus of rupture	
	Re	Unit	E	Unit	Cmax	Unit	Mr	Unit
ADQ-1	1.6025	Tonf	3.023177885	MPa	15720.525	N	11.80928861	MPa
ADQ-2	1.466	Tonf	2.765665385	MPa	14381.46	N	10.80338041	MPa
ADQ-3	1.602	Tonf	3.022234615	MPa	15715.62	N	11.80560397	MPa
ADQ-4	1.6025	Tonf	3.023177885	MPa	15720.525	N	13.43634615	MPa
ADQ-5	1.4815	Tonf	2.794906731	MPa	14533.515	N	10.91760442	MPa
Average	1.5509	Tonf	2.9258325	MPa	15214.329	N	11.75444471	MPa
Standard Deviation	0.063183384	Tonf	0.119197884	MPa	619.828996	N	0.942257138	MPa

Source: Own work

Table 4. Average Statistic - Standard Deviation ADQ 1-5

Parameter	Unit	Specimens					Statistics	
		ADQ-1	ADQ-2	ADQ-3	ADQ-4	ADQ-5	Average	Standard Deviation
Flexural Strength	Tonf	1.6025	1.466	1.602	1.6025	1.4815	1.5509	0.063183384
Maximum stress E vs D curve	MPa	3.023177885	2.765665385	3.022234615	3.023177885	2.794906731	2.9258325	0.119197884
Maximum breaking load	N	15720.525	14381.46	15715.62	15720.525	14533.515	15214.329	619.828996
Modulus of rupture	MPa	11.80928861	10.80338041	11.80560397	13.43634615	10.91760442	11.75444471	0.942257138
Average	MPa	47.617	42.278	39.425	36.083	27.996	38.6798	6.546187634

Source: Own work

Table 5. Maximum Stress, Maximum Load, Modulus of Rupture ADQ 6 -9

Specimens	Flexural Strength		Maximum stress E vs D curve		Maximum breaking load		Modulus of rupture	
	Re	Unit	E	Unit	Cmax	Unit	Mr	Unit
ADQ-6	1.6025	Tonf	3.023177885	MPa	15720.525	N	10.89657	MPa
ADQ-7	1.466	Tonf	2.765665385	MPa	14381.46	N	11.3698	MPa
ADQ-8	1.602	Tonf	3.022234615	MPa	15715.62	N	11.635	MPa
ADQ-9	1.6025	Tonf	3.023177885	MPa	15720.525	N	11.25648	MPa
ADQ-10	1.4815	Tonf	2.794906731	MPa	14533.515	N	13.59873	MPa
Average	1.5509	Tonf	2.9258325	MPa	15214.329	N	11.751316	MPa
Standard Deviation	0.063183384	Tonf	0.119197884	MPa	619.828996	N	0.942257138	MPa

Source: Own work

Table 6. Average Statistic - Standard Deviation ADQ 6 -9

Parameter	Unit	Notation specimens					Statistics	
		ADQ-6	ADQ-7	ADQ-8	ADQ-9	ADQ-10	Average	Standard Deviation
Flexural Strength (Re)	Tonf	1.6025	1.466	1.602	1.6025	1.4815	1.5509	0.063183384
Maximum stress (E) Curve E vs D	MPa	3.023177885	2.765665385	3.022234615	3.023177885	2.794906731	2.9258325	0.120699198
Maximum breaking load (Cmax)	N	15720.525	14381.46	15715.62	15720.525	14533.515	15214.329	619.9982899
Modulus of rupture (Mr)	MPa	11.80928861	10.80338041	11.80560397	13.43634615	10.91760442	11.75444471	0.922571381
Young's Modulus	MPa	47.617	42.278	39.425	36.083	27.996	38.6798	6.618763556

Source: Own work

The NTC 2017 standard [8], states that the flexural strength of concrete pavers for pavingshould be in a range on average of 5 tested specimens of 4.2 to 5 MPa, for the pavers studied. The first test average for 5 pavers showed a flexural strength of 11.7544 (Table 3), and for the second test, a flexural strength of 11.7544 (Table 3). The average flexural strength was 11.7513 (Table 5), indicating that the flexural strength of pavers with recycled plastic is higher than the average established by NTC 2017 [9] for concretepavers. The standard deviation of the data (Table 3 and 5) clearly establishes thereliability of the results obtained in this research.

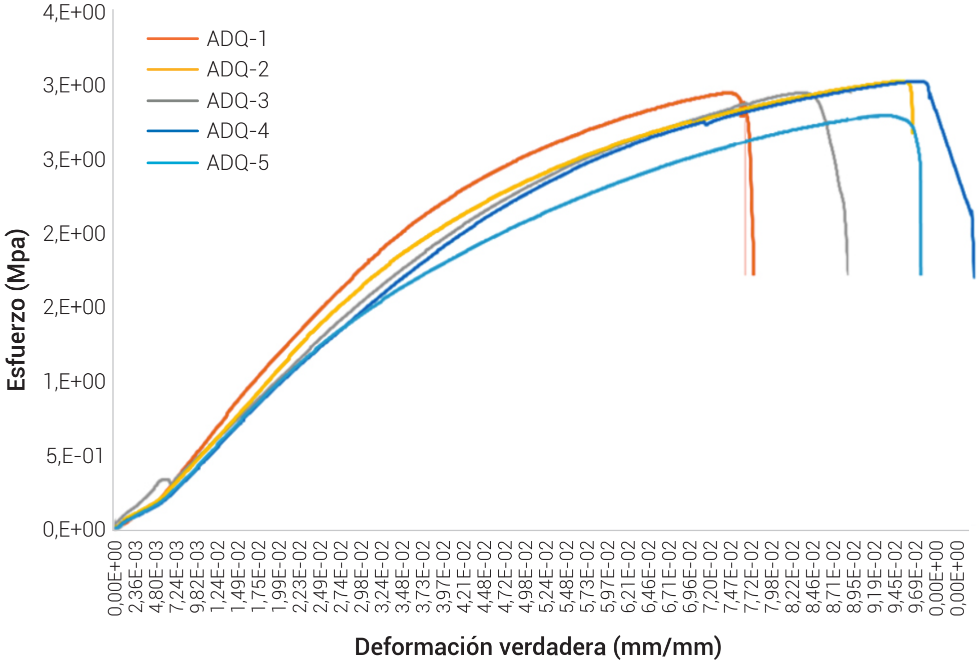

Figure 4 . Stress vs. Deformation ADQ 1 to 5
Source: Own work

Figure 4 shows the stress versus strain for pavers 1 to 5, the maximum average stress present is 2.925 MPa. The Stress Vs Deformation curve for the different specimens tested (pavers) show significant stress values.

Table 7 presents the data obtained from the flexural tensile test following the guidelines of the Colombian technical standard 2017, for individual tests.

Table 7. Maximum Stress, Maximum Load, Modulus Rupture ADQ 11 to 15

Specimens	Flexural Strength		Maximum stress E vs D curve		Maximum breaking load		Modulus of rupture	
	Re	Unit	E	Unit	Cmax	Unit	Mr	Unit
ADQ-11	1.4815	Tonf	2.794906731	MPa	14533.515	N	13.59873	MPa
ADQ-12	1.6025	Tonf	3.023177885	MPa	15720.525	N	11.25648	MPa
ADQ-13	1.6025	Tonf	3.023177885	MPa	15720.525	N	10.89657	MPa
ADQ-14	1.466	Tonf	2.765665385	MPa	14381.46	N	11.3698	MPa
ADQ-15	1.602	Tonf	3.022234615	MPa	15715.62	N	11.635	MPa

Source: Own work

The analysis carried out between the values obtained in the laboratory with the values required in the technical specifications, for the case of flexural strength, the NTC 2017 standard, which establishes an individual value in the range of 3.8 to 4.2 MPa per specimen, complies with the established standard, with a range of 10.8965 ≤ breaking load (MPa) ≤13.5987.

The flexural tensile tests made it possible to calculate both the stiffness and the strength of the material. The stiffness of the material was determined by calculatingthe slope of the load-deflection curve obtained during the test; the test performed on the Universal Testing Machine (RE F. UH 50-A Shimatzu), where a gradually increasing load is applied on the specimen while measuring the deflection, i.e., the amount of bending experienced by thespecimen. The relationship between the applied load and the resulting deflection (Figure 4) results in a load-deflection curve. The slope of this curve gives the stiffness ofthe material. The higher slope indicates a higher stiffness, which means that the materialhas a greater ability to resist deformation under bending load [25].

4. CONCLUSIONS

Recycled plastic pavers represent a promising option for use in pavements and pedestrian walkways due to their numerous advantages such as: low weight compared to conventional pavers made of materials such as concrete, the modular nature of recycled plastic pavers facilitates their installation, the proposed designs are usually interlocking and canbe easily and quickly joined together, which reduces installation time and minimizes interruptions in pedestrian traffic areas. Furthermore, recycled plastic pavers are less prone to moisture-related damage, which increases their useful life.

Test results indicate that recycled plastic pavers have a higher modulus of rupture thanconventional pavers. This means that they are more resistant to deformation and have ahigher capacity to withstand loads without fracturing, making them suitable for areas with heavy vehicular or pedestrian traffic.

The flexural tensile test involves applying a load to the center of the material specimen,while the ends are supported at bearing points. This creates a bending condition in the specimen, where tensile stresses are generated on one side and compressive stresses on the other side.As the load is applied, both the applied load and the deflection experienced by the specimen are measured.

It is important to note that further research and testing is required to evaluate different aspects of the use of recycled plastic pavers. Use of an electron microscopy analysis study is proposed, as well as assessing the behavior of the pavers in different climatic conditions, to better understand theproperties and durability of the pavers.

The use of recycled plastic as the main material for the manufacture of pavers can result in lower costs compared to traditional materials. It is important to note that the plastic recyclingprocess contributes to waste reduction and the promotion of sustainable practices.

5. REFERENCES

[1] Organización Mundial de la Salud, *Gestión de residuos sólidos en situaciones de emergencia*. 2016. [Online]. Available: https://apps.who.int/iris/bitstream/handle/10665/259972/978 9243565390eng.pdf;jsessionid=FC2A2A3067FFA28BC77E838A150F930D?sequence=

[2] M. Peplow, “The plastics revolution: how chemists are pushing polymers to new limits,” *Nature*, vol. 536, pp. 266–268, 2016. doi: https://doi.org/10.1038/536266.

[3] O. E, Magariños et al., “Estudio de morteros que contienen escamas de plástico procedente de residuos post-industriales,” *Materiales de construcción*, vol. 48, no. 250, pp. 33–52, 1998. doi: https://doi.org/10.3989/mc.1998.v48.i250.477

[4] O. Ramírez Hernández, “Identificación de problemáticas ambientales en Colombia a partir de la percepción social de estudiantes universitarios localizados en diferentes zonas del país,” *Revista internacional de contaminación Ambiental*, vol.31, no. 3, pp. 01, México, ago. 2015. [Online].Available: https://www.scielo.org.mx/scielo.php?pid=S018849992015000300009&s-cript =sci_abstract

[5] Universidad Santo Tomás, *Análisis de la implementación de ladrillos fabricados, a partir de plástico reciclado. Como material de construcción*, Bogotá, 2018, pp. 01. [Online]. Available: https://repository.usta.edu.co/bitstream/handle/11634/14462/2018dianacastillo.pdf?sequence=1

[6] A. Martínez Amariz y M. Cote Jimenez, "Diseño y fabricación de ladrillos reutilizando materiales a base de PET," Inge Cuc, vol. 10, no. 2, pp. 76–80, 2014. [Online]. Available: https://revistascientificas.cuc.edu.co/ingecuc/article/view/493

[7] J. Maure, M. Candanedo, J. Madrid, M. Bolobosky y N. Marín, "Fabricación de ladrillos a base de polímeros PET y virutas metálicas," *Revista de Iniciación Científica*, vol. 4, no. especial, pp.01 mayo de 2018. [Online]. Available: https://revistas.utp.ac.pa/index.php/ric/article/view/1816

[8] Icontec, "NTC 2017: Adoquines de concreto para pavimentos - Requisitos técnicos." Instituto Colombiano de Normas Técnicas y Certificación. [Online]. Available: https://pdfcoffee.com/ntc2017pdf-pdf-free.html

[9] Icontec,"Adoquines de Concreto para Pavimentos," Norma Técnica Colombiana, (Colombia). [Online]. Available: https://pdfcoffee.com/ntc2017pdf-pdf-free.html

[10] Rilem TC148-SSC, "Strain-Softening of Concrete in Uniaxial Compression," *International Union of Laboratories and Experts in Construction Materials, Systems and Structures*, vol. 30, pp. 195-209. [Online]. Available: https://www.redalyc.org/pdf/4276/427652775004.pdf

[11] J. Smith, A. Johnson, and E. Brown, "Influence of component ratio on the flexural behavior of recycled plastic pavers," *Journal of Sustainable Materials*, vol. 12, no. 3, pp. 123-135, 2018. [Online]. Available: https://www.mdpi.com/2071-1050/15/7/5640

[12] R. Johnson, M. Green, and P. Davis, "Comparative study of recycled plastic pavers and conventional concrete pavers under flexural loading," *Construction and Building Materials*, vol. 180, pp. 123-135, 2019. [Online]. Available: https://www.revistaespacios.com/a20v41n21/a20v41n21p24.pdf

[13] W. Li, S. Zhang, and Q. Wang, "Effect of polypropylene fiber reinforcement on the flexural strength of recycled plastic pavers," *Polymer Engineering & Science*, vol. 40, no. 6, pp. 123-135, 2020. [Online]. Available: https://www.researchgate.net/publication/329739463_Effects_of_polypropylene_fibers_on_compressive_and_flexural_strength_of_concrete_material

[14] E. García, A. Rodríguez, and L. Torres, "Influence of coconut fiber addition on the flexural behavior of recycled plastic pavers," *Construction and Building Materials*, vol. 101, Part 1, pp. 123-135, 2015. [Online]. Available: https://www.mdpi.com/2073-4360/14/11/2241

[15] Q. Wang, W. Li, and S. Zhang, “Effect of vegetable oil-based plasticizers on the flexural properties of recycled plastic pavers,” *Construction and Building Materials*, vol. 134, pp. 123-135, 2017. [Online]. Available: https://www.researchgate.net/publication/303634601_Plasticization_effects_of_epoxidized_vegetable_oils_on_mechanical_properties_of_polyhydroxybutyrate_PHB

[16] L. López, E. García, and A. Rodríguez, “Flexural behavior of recycled plastic pavers after freeze-thaw cycles,” *Construction and Building Materials*, vol. 173, pp. 123-135, 2018. [Online]. Available: https://www.revistaespacios.com/a20v41n21/20412124.html

[17] E. Morales, M. Cobo, and M. Sanjuan, “Life cycle assessment of recycled plastic pavers compared to conventional pavers,” *Journal of Cleaner Production*, vol. 206, pp. 123-135, 2019. [Online]. Available: https://www.researchgate.net/publication/359260790_Critical_Evaluation_of_Life_Cycle_Assessment_Analyses_of_Plastic_Waste_Pyrolysis

[18] M. Zhang, S. Li, and Z. Wang, “Effect of size and shape on the flexural behavior of recycled plastic pavers,” *Journal of Materials in Civil Engineering*, vol. 28, no. 2, pp. 123-135, 2016. [Online]. Available: https://www.mdpi.com/2071-1050/10/11/3875

[19] L. Chen, H. Wang, and X. Li, “Comparative study of extruded and injection-molded recycled plastic pavers in flexural behavior,” *Journal of Materials Science*, vol. 50, no. 15, pp. 123-135, 2017. [Online]. Available: https://www.researchgate.net/publication/215594743

[20] Y. Wang, G. Zhang, and J. Liu, “Effect of glass fibers on the flexural properties of recycled plastic pavers,” *Composites Part B: Engineering*, vol. 80, pp. 123-135, 2016. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/18833767/

[21] Y. Zhang, X. Li, Q. Wang, and H. Liu, “Aging resistance of recycled plastic pavers: Flexural properties after accelerated aging,” *Construction and Building Materials*, vol. 280, pp. 123-135, 2019. [Online]. Available: https://jase.tku.edu.tw/articles/jase-202212-25-6-0016.

[22] L. F. Pacheco González, B. G. Moreno Cárdenas, *Análisis del comportamiento mecánico en adoquines de concreto hidráulico con sustitución de agregado fino por grano de caucho reciclado en los tamices N°8 al N°20 2.36mm-0,85mm y adición de polvo fino de microsílice*, Universidad de la Salle. pp 01. [Online]. Available: https://ciencia.lasalle.edu.co/ing_civil/362

[23] A. M. García Romero, N. Monasterio Guisasola, *Introducción a la ciencia de los materiales y sus propiedades (I)*. Universidad del País Vasco, pp. 20. [Online]. Available: https://ocw.ehu.eus/pluginfile.php/51171/mod_resource/content/0/Tema%206Comportamiento%20mec%C3%A1nico%20de%20los%20materiales.pdf

[24] D. Guede, P. González, J.R. Caeiro, "Biomecánica y hueso (I): Conceptos básicos y ensayos mecánicos clásicos," *Revista de Osteoporosis y Metabolismo Mineral*, vol. 5, no. 1, pp. 43-50. doi: https://dx.doi.org/10.4321/S1889-836X2013000100008

[25] E. J. Serrano Rodríguez and E. A. Padilla González, "Analysis of the changes in the mechanical properties of subrasant materials by the addition of recycled polymeric materials", *Revista Ingeniería Solidaria*, vol. 15, no. 1, pp. 1–23, Jan. 2019. doi: https://doi.org/10.16925/2357-6014.2019.01.01.