Flexural strength tests of a composite concrete and coffee husk cobblestone for use in pedestrian and light vehicular traffic surfaces, according to NTC 2017 Standard

Pruebas de resistencia a la flexotracción de un adoquín como material compuesto en concreto y cascarilla de café, para superficies de tránsito peatonal y vehicular liviano, según la Norma NTC 2017

Ensaios de resistência à flexão de uma pedra de pavimentação como material composto em betão e casca de café, para superfícies de tráfego pedonal e veículos ligeiros, de acordo com a Norma NTC 2017

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Abstract

Introduction: The article is the product of the research "Characterization of a composite concrete and coffee husk cobblestone for use in pedestrian and light vehicular traffic surfaces", developed at the Universidad Distrital Francisco José de Caldas, in 2022.

Objective: Evaluate the viability of using coffee husks as a partial substitute in the manufacture of cobblestone according to the Colombian Technical Standard "NTC 2017, Concrete cobblestones for Paving".

Methodology: The design, manufacture and analysis of cobbles was developed under the Colombian Technical Standard 2017. The coffee husk employed for the manufacture of the cobblestones was used in mixtures equivalent to 10%, acting as a substitute for sand and cement

Conclusions: The experimental data suggests that the coffee husk mixture should not exceed 10%. The Flexural Strength values increased significantly in comparison to the mixtures whose coffee husk percentages were in ranges between 0.5 and 1.0%.

Originality: Following the bibliographical review, we propose and elaborate upon the idea of using composite concrete and coffee husk cobblestone for pedestrian and light vehicular traffic surfaces

Limitations: There were no limitations as the materials used are of conventional use.

Keywords: Cobblestone, climate change, coffee husk, concrete, modulus of rupture.

Resumen

Introducción: El artículo es producto de la investigación Caracterización de un adoquín como material compuesto en concreto y cascarilla de café, para superficies de tránsito peatonal y vehicular liviano, desarrollada en la Universidad Distrital Francisco José de Caldas, en el año 2022

Objetivo: Evaluar la cascarilla de café como sustituyente parcial en la fabricación de un adoquín según la Norma Técnica Colombiana NTC 2017 Adoquines de concreto para Pavimento, como una alternativa ecológica que permita evaluar su viabilidad.

Metodología: La presente investigación propone la caracterización de un adoquín, como material compuesto en concreto y cascarilla de café, para superficies de tránsito peatonal y vehicular liviano. El diseño, fabricación y análisis de adoquines, se desarrolló bajo la Norma Técnica Colombiana 2017. La cascarilla de café utilizada para la fabricación de los adoquines se utilizó en mezclas equivalentes al 10%, actuando como sustituto de arena y cemento.

Conclusiones: Los datos experimentales dieron como resultado que la mezcla de cascarilla de café debe estar en un rango menor al 10%, los valores de resistencia a la Flexotracción aumentaron significativamente en comparación a las mezclas cuyos porcentajes de cascarilla se encontraban en rangos entre 0,5 y 1,0% de cascarilla de café.

Originalidad: En la revisión bibliográfica se encuentra estudios del comportamiento del concreto con adición de cascarilla de café, proponemos elaborar adoquines como material compuesto en concreto y cascarilla de café, para superficies de tránsito peatonal y vehicular liviano que cumpla con los requerimientos mínimos establecidos en la Norma Técnica Colombia NTC 2017.

Limitaciones: No se presentaron ya que los materiales empleados son de uso convencional.

Palabras clave: Adoquín, cambio climático, cascarilla de café, concreto, módulo de rotura.

Resumo

Introdução: O artigo é produto da pesquisa de caracterização de um paralelepípedo como material compósito em concreto e casca de café, para superfícies de tráfego de pedestres e veículos leves, desenvolvida na Universidade Distrital Francisco José de Caldas, no ano de 2022.

Objetivo: Avaliar a casca de café como substituto parcial na fabricação de uma pedra de pavimentação de acordo com a Norma Técnica Colombiana NTC 2017 Pavimentos de concreto para pavimentação, como uma alternativa ecológica que permite avaliar sua viabilidade.

Metodologia: Esta pesquisa propõe a caracterização de um paralelepípedo, como material compósito em concreto e casca de café, para superfícies de tráfego de pedestres e veículos leves. O projeto, fabricação e análise de pedras de pavimentação foi desenvolvido sob a Norma Técnica Colombiana 2017. A casca de café utilizada para a fabricação das pedras de pavimentação foi utilizada em misturas equivalentes a 10%, atuando como substituto de areia e cimento.

Conclusões: Dados experimentais mostraram que a mistura de casca de café deveria estar no intervalo inferior a 10%, os valores de resistência à flexão aumentaram significativamente em comparação com as misturas cujas percentagens de casca estavam no intervalo de 0,5 a 1,0% de casca de café.

Originalidade: Na revisão bibliográfica encontram-se estudos do comportamento do concreto com adição de casca de café, propomos a elaboração de lajes como material composto em concreto e casca de café, para superfícies de tráfego de pedestres e veículos leves que atendam aos requisitos mínimos estabelecido na Norma Técnica Colômbia 2017.

Limitações: Não foram apresentadas pois os materiais utilizados são de uso convencional.

Palavras-chave: Casca de café, concreto, módulo de ruptura, mudanças climáticas, paralelepípedo.

1. INTRODUCTION

Climate change is currently established as a global emergency that requires coordinated solutions at the national and international levels. With the aim of mitigating the environmental impact generated and its negative consequences, the Paris Agreement emerged at COP21, accepted by 197 countries on December 12, 2015. [1] The main objective established within the treaty, that includes Colombia, is to reduce greenhouse gas emissions; exploring and improving upon sustainable development forms part of the solution. Recently at COP 26, Colombia led the negotiations of the Global Balance of the Paris Agreement. Likewise, Colombia was chosen to represent the Latin American and Caribbean region in strategic committees on compliance with the Agreement and adaptation to climate change [2].

Colombia has been increasing its efforts to reduce greenhouse gas emissions generated by large industries, encouraging different companies to create products with natural additives that are more environmentally friendly, allowing them to be environmentally sustainable and encouraging the preservation of resources through the concepts of reduction, reuse, and recycling. To meet this need, it is important to improve existing applications and develop new ecological alternatives based on the use of agroindustry, which generates large quantities of solid waste, rich in organic matter, that due to their biodegradable nature can be safely disposed of and can substitute new value-added products. In Colombia, most of the by-products generated by agroindustry are incinerated or dumped in water streams. Some are included in the production of compost, vermicompost, detoxification, solid biofuel, ethanol, biogas, adsorbents, mushrooms, energy drinks, energy bars and fermentation studies [3].

The final disposal of agro-industrial waste generates an economic loss and significantly alters the environment due to the high consumption for washing and separation, which varies from 0.1 to 0.3 L of water per liter of fruit, while in peeling and/or pulping, the consumption is 3 to 5 L of water per liter of fruit [4]. Consequently, if this water is discharged directly into effluents or not properly treated it can have a great negative impact, with serious consequences such as degrading the oxygen level in the water, which can kill swathes of flora and fauna, clogging waterways, and further contributing to anaerobic conditions. This hostile environment, generated by the discharge of pulping water, favors the growth of health-threatening bacteria, generating a bad odor and dark appearance, caused by toxic chemicals such as tannins, phenols, and alkaloids [4].

The use of organic material for construction is currently being studied with the aim of replacing traditional materials, such as cement and concrete, among others, because their continuous exploitation generates high concentrations of toxic substances that are emitted into the atmosphere. For this reason, the reuse of agro-industrial waste (eggshells, sawdust, coffee husks, rice husks, sugar cane, etc.) is being sought as an alternative. In some research, several types of components have been used as a possible sustainable alternative: Rubber fibers when mixed with concrete provide an effect that is inversely proportional to its resistance to compression [5], sugarcane bagasse ash in the concrete mix, led to the most optimal mechanical properties [6]. Eggshell ash, when substituted in proportions of 1.5% generates an increase in flexural strength of 8.62 % with respect to the mix without ash substitution [7]. Cane bagasse ash with a drying time of 7 days achieves its maximum value with a 40% substitution, but increasing the percentage further decreases the strength of the concrete. [8]

Some studies have been carried out on the behavior of concrete with the addition of coffee husks that make it a light compound, with a silicon percentage of 15% in its chemical structure [9]. One of the main sources of income for the agricultural sector in Colombia is the commercialization of coffee with a high contribution to the country's economy [10]. Its properties make it optimal for this research. Coffee husk, as agro-industrial waste, represents 15% of the agricultural GDP; by 2022, coffee production will be 13.2 million bags [11]. During the production of coffee powder, the only part that is used is the bean, and all other parts, such as husk, parchment, mucilage, pulp, and skin, known as by-products, are discarded and can contaminate the environment. In other words, more than 50% of the coffee fruit is discarded when it could have a potential use in the pharmaceutical, food, cosmetic, construction, and other industries [12].

The objective of this study is to evaluate the viability of using coffee husks as a partial substitute in the manufacture of a cobblestone, according to the Colombian Technical Standard "NTC 2017, Concrete cobblestones for Paving".

2. MATERIALS AND METHODOLOGY

A. Material Used

Materials used for the manufacture of the test specimens were as follows: Estructural Max cement manufactured by Argos (Colombia) and coffee husks from the El Porvenir Specialty Coffee Association Group, located in the south of the municipality of Isnos-Huila (Colombia).

Physical properties of Coffee Husk

The average particle size of the coffee husk was 250 μm, procured from an industrial mill for specialty coffee at the Faherjos factory (located in Isnos-Huila).

Aggregate properties

It was verified that the aggregates from the department of Huila complied with the specifications of Colombian Technical Standard 174 [13] in the manufacture of concrete mixtures. Table 1 presents the general characteristics of the aggregates used for the manufacture of the specimen.

Table 1. Characteristics of the Aggregates Used for the Manufacture of the Specimens.

Characteristic	Thick Aggregate	Fine Aggregate (sand)
Fineness modulus	4,23	2,13
Bulk density (g/cm^3)	2,64	2,73
Absorption (%)	2,98	3,36

Source: Own work

B. Mix Design

Previous research was considered, determining the ratio of rough and fine aggregate with the percentage of coffee husk at 10%, behaving as filler (sand substitution) and pozzolan (cement substitution). The ratio was 1:2:3 as shown in Table 2. The specimens were manufactured according to the NTC 2017 standard [14] which establishes the following cobblestone dimensions: 0.2 m in length, 0.1 m in width and 0.06 m in thickness.

Table 2. Dosage of Cement. [15]

Type of Concrete	Strength (kg/cm^2)	Strength (MPa)	Strength (psi)	Materials			
				Cement (kg)	Sand (m^3)	Gravel (m^3)	Water (L)
1:2:2	245	24	3500	420	0,67	0,67	220
1:2:3	210	21	3000	350	0,56	0,84	180
1:2:4	175	17	2500	300	0,48	0,96	170
1:3:4	140	14	2000	260	0,63	0,84	170

The calculation for the volume of the mixture of the 5 specimens is presented in equation (1)

$$V=(L*W*H)*N \tag{1}$$

Where:

V: Volume in m^3

L: Length in m

W: Width in m

H: Height in m

N: Number of cobblestones

The result of the total volume was 0.006 m^3. The dosage of cement, sand and gravel per cubic meter was made considering the type of concrete 1:2:3 presented in Table 2.

Table 3 presents the final mix design for the 1:2:3 type of concrete, substituting 0% coffee husk and 10% for the total mix.

Table 3. Final Mix Design.

Materials Quantity (m^3)		
Materials	**Mix**	
	0% Coffee husk	10% Coffee husk
Cement	0,00168	0,00138
Sand	0,00336	0,00306
Gravel	0,00504	0,00504
Water	0,00108	0,00108
Coffee husk	0	0,0006

Source: Own work

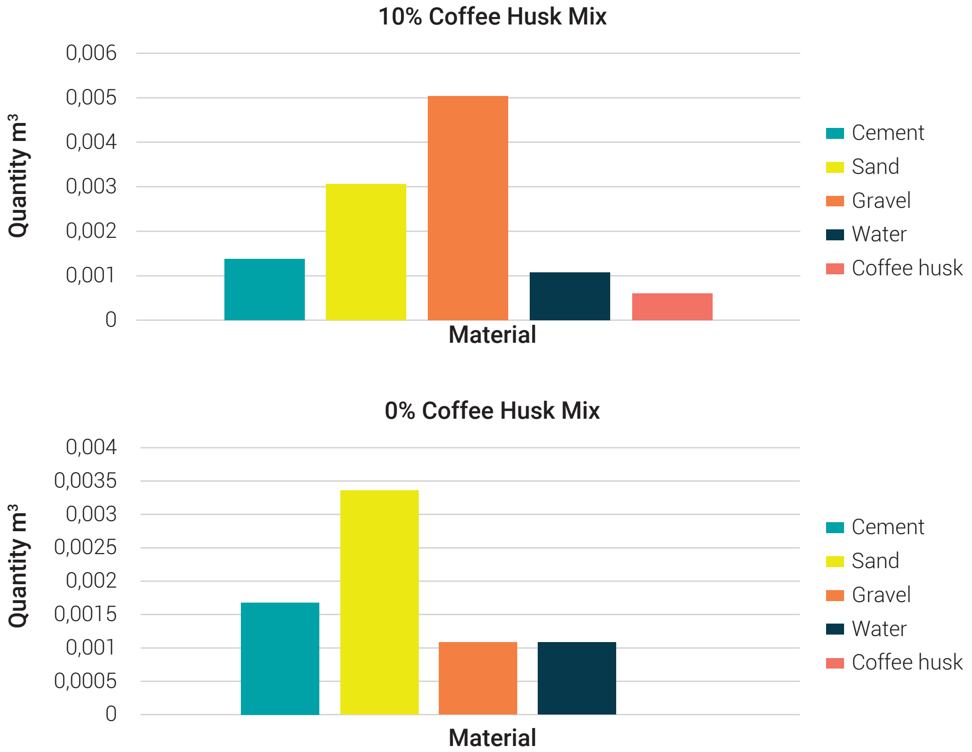

Figure 1. Material Quantity ratio in m^3.
Source: Own work

Figure 1 shows the ratio of materials in m³ for each of the mixes, where the graph of the mix design, substituted with 10% coffee husk, shows the ratio of cement and aggregate in which coffee husk acts in substitution of cement and sand (5% each).

C. Equipment and Testing

Two molds were manufactured in laminated wood of 0.2 m in length, 0.1 m in width and 0.06 m in thickness for the experimentation of the final mix, substituting 10% coffee husk for the total mix, according to the Colombian Technical Standard 2017. Figure 2 shows the result per test specimen.

Figure 2. Result of the Final Mix with 10% of Coffee Husk.
Source: Own work

Drying was carried out at room temperature (T=23°C, Municipality of Isnos-Huila, Colombia), with an estimated drying time of 28 days.

For the case study, 5 specimens were manufactured with the dimensions shown in Table 4.

Table 4. Specimen Dimensions.

	Cobblestone Lengths (m)		
Specimen	**Length**	**Width**	**Height**
C/U	0,2	0,1	0,06

Source: Own work

Figure 3 shows the 5 specimens.

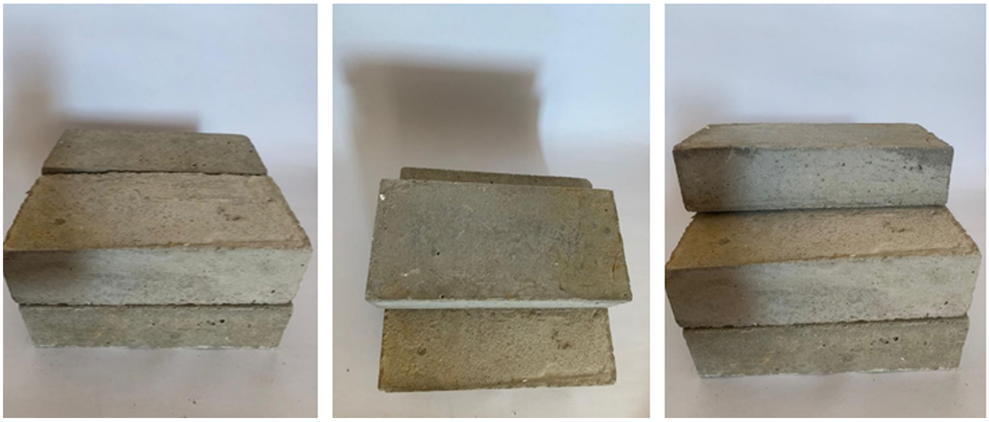

Figure 3. Prototypes of the 5 Specimens.
Source: Own work

D. Flexural Strength Tests

The 5 specimens were subjected to Flexural Strength tests, using the Universal Testing Machine (REF. UH 50-A Shimatzu). Figure 4 shows the arrangement of each specimen in the machine.

Figure 4. Arrangement of Specimens in the Universal Testing Machine.
Source: Own work

Each specimen was placed in the testing machine with the support surface facing down. The load is applied on the section area of the wearing side, and it forms a parallel line with the support points, 10 mm to the inside of the minor sides of the rectangle. The distance between supports is 15 cm above the support side, according to the NTC 2017 Standard [14].

Figure 5 shows the specimens subjected to the maximum load to reach rupture:

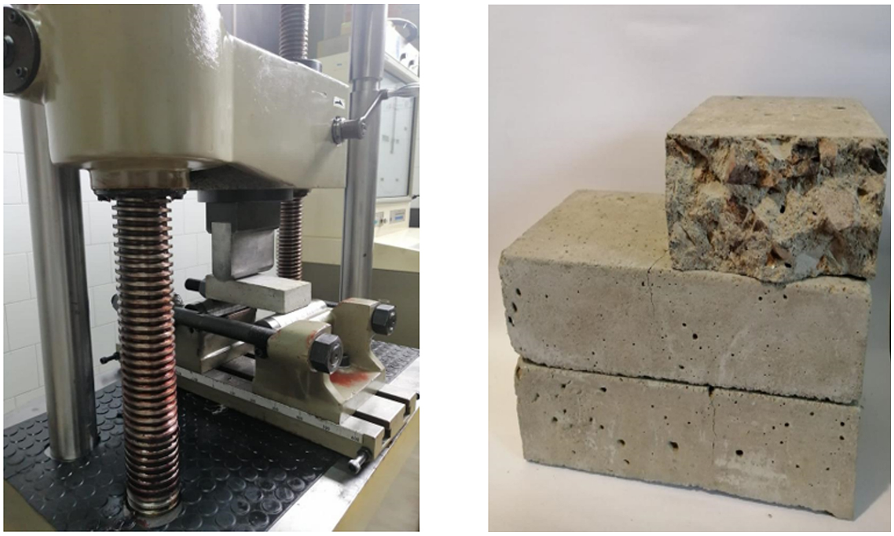

Figure 5. Maximum Load to Reach Rupture.
Source: Own work

3. RESULTS

Table 5 shows the data obtained from the Flexural Strength test corresponding to a sample of 5 specimens tested using the Colombian technical standard 2017.

Table 5. Flexural Strength Test Results per Specimen.

	Specimen	Max. Stress (MPa)	Max. Deflection (mm)	Max. Load (kN)
Cobblestone	1	3,59416	0,992	4,11879
	2	3,1749	0,688	4,35415
	3	2,58712	1,302	3,54805
	4	2,99471	1,643	4,10703
	5	2,91891	1,211	4,00307
Average		**3,05396**	**1,1672**	**4,026218**

Source: Own work

Figure 6 shows that Specimen 1 obtained the maximum stress value of 3.5941 MPa. The definition of elastic deformation is uncertain, since the stress-strain relationship in concrete is not clearly defined through a straight line at usual stress magnitudes, nor are its deformations completely recoverable. Leaving aside the plastic deformations of this concept, the lower section of the stress-strain curve, which is relatively straight, can be connoted as elastic. Nonetheless, the elasticity modulus is defined as the modulus tangent to a defined point on the stress-strain curve according to ASTM Designation: C 469 – 94 [16]. Test 1 indicates a curved fragment defined by a trajectory that starts at the origin and ends at the time when the cobblestone reaches the maximum resistance before breaking. At this point the curve is at a tangent to the horizontal [17].

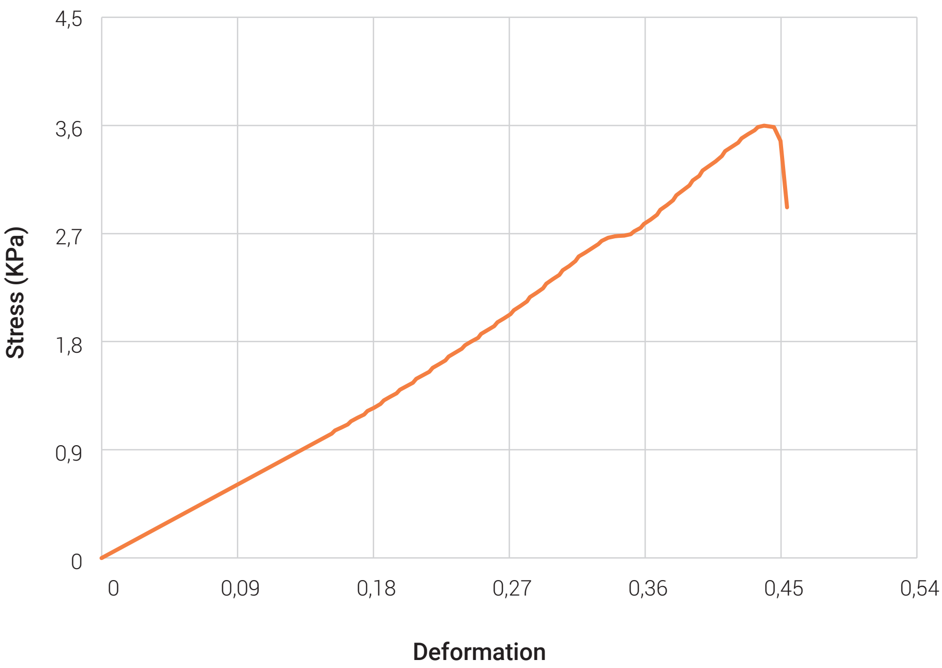

Figure 6. Flexural Strength: Specimen 1.
Source: Own work

Figure 7 represents the stress versus strain for the 4 tests performed on the remaining specimens. Where the maximum expected rupture stress is 3.1749 MPa corresponding to Specimen 2, and the lowest expected rupture stress is 2.58712 MPa for Specimen 3. A slight increase in strength can be observed in Specimens 4 and 5 in relation to Specimen 3. On average, the five specimens presented a strength of 3.05396 MPa.

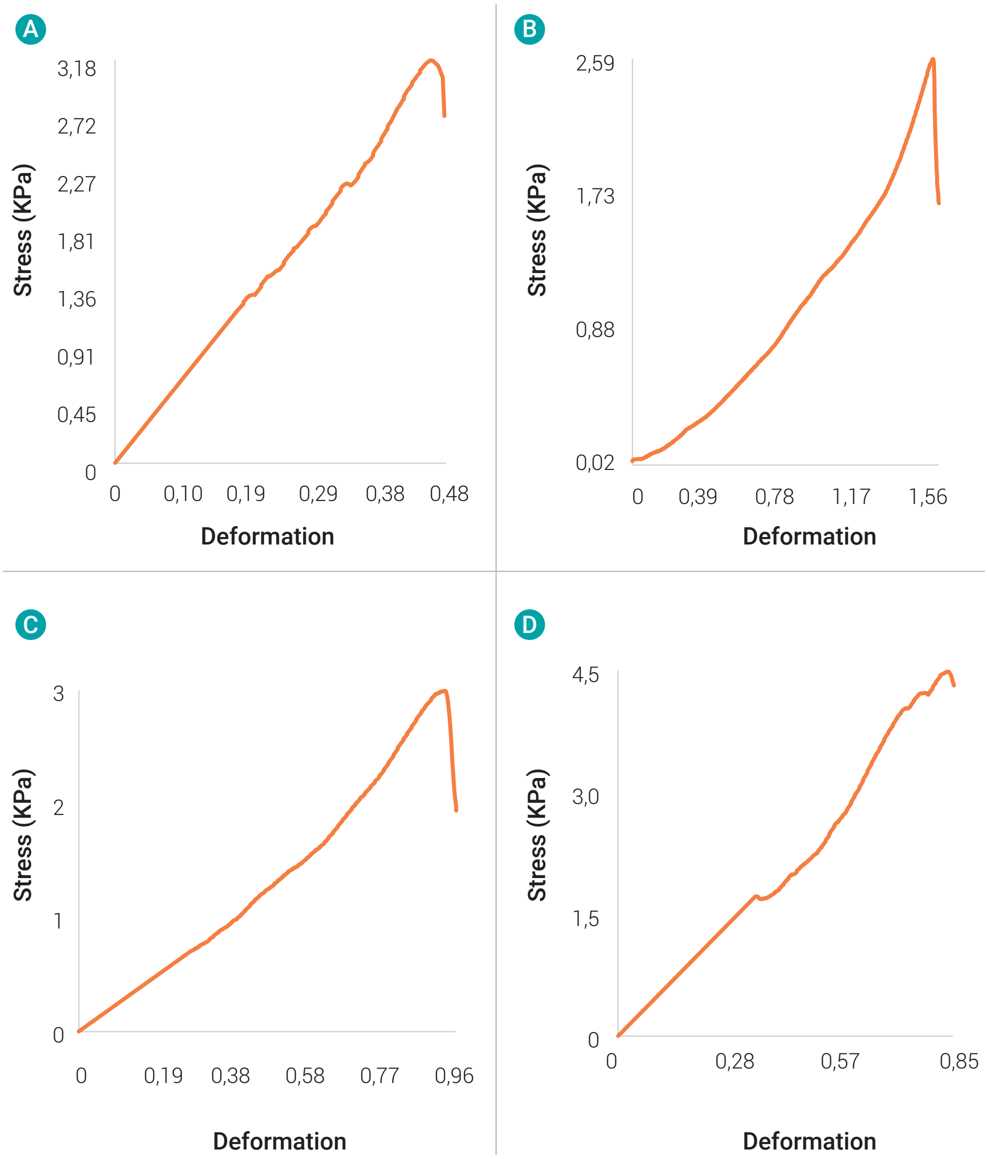

Figure 7. Flexural Strength: a). Specimen 2; b). Specimen 3; c). Specimen 4; and d) Specimen 5.
Source: Own work

The specimens with concrete type 1:2: 3 that were substituted with 10% of coffee husk for the total of the mixture, present an average rupture strength for the five specimens of 3.0499 MPa, being below the minimum values accepted to be used as constructive elements for: pedestrian traffic, vehicular traffic on pneumatic tires, cargo terminals, airports and distributed static loads, according to the NTC 2017 standard; which describes that the appropriate range of specimens must present a modulus of rupture at 28 days of curing of 4.2 MPa on average for the 5 specimens and 3.8 MPa individually. It is concluded that the mix design with 10% substitution is not sufficient to maintain the concrete strength requirements for use according to NTC 2017. Because it is necessary to implement a more detailed process to the scale to achieve a higher rupture strength, it is important to perform a previous treatment that protects the scale from the alkaline medium of the cement.

4. CONCLUSIONS RECOMMENDATIONS

Based on the literature reviewed, it is important that the coffee husk, as a vegetable aggregate, should be given a previous treatment to prevent its deterioration as the result of the alkaline environment of the cement. For the current research, a previous protection of the husk to the alkaline medium was not considered. Therefore, it is suggested to use linseed oil, calcium hydroxide or agricultural lime. It is thus worthwhile to determine whether the variables of protection to the coffee husk increase its resistance to all types of external factors (sunlight, contamination, water, wear) and not only to the alkaline medium of the cement.

It is recommended to study the drying variable at 7, 14, 21 and 56 days to observe if there is a relationship between the drying time and the resistance behavior of the coffee husk, as well as variables of solar radiation and humidity that allow us to verify physical-chemical changes in the concrete [18].

Considering the results obtained with 10% of coffee husk for the total of the mix, it is advisable to carry out test studies with a replacement of 5%, 2%, 1% and 0.5% of coffee husk and to observe if the mechanical behavior of the mixes increases the rupture resistance in the specimens.

5. CONCLUSIONS

The coffee husks from the municipality of Isnos-Huila meet the requirements for mix design and final finishing, especially in the use of architectural concrete. As a 10% replacement of coffee husk in the total mix, it does not fulfill the resistance criteria for pedestrian and light vehicular use, according to NTC 2017.

From the obtained results, it is feasible to conclude that it is recommended to have low replacement percentages of coffee husk, since the resistance tends to decrease significantly as the percentages of coffee husk increase, with the aim of maintaining the mechanical properties and workability of the mix. In accordance with previous research, it is possible to obtain better resistance results with substitutions of percentages between 0.5 and 1.0% [8].

Although an approximate resistance of 100% was not obtained, it is feasible to make mixes with coffee husk substitution to be used in structures with conventional uses such as architectural concrete; where it is viable to obtain criteria of cohesion, durability, resistance, and homogeneity among the materials, in the same way as with ordinary aggregate concrete, provided the dosage guidelines, mix design and adequate curing time are followed.

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