Revista Ingeniería de Construcción RIC
Vol 37 Nº2 2022 www.ricuc.cl
DOI: 10.7764/RIC.00032.21

Evaluation of the physical and mechanical properties of a paving block with added ash from artisanal brick kilns

Evaluación de las propiedades físico-mecánicas de un adoquín adicionando cenizas de ladrilleras artesanales

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Fecha de Recepción:12/02/2022
Fecha de Aceptación: 22/06/2022
Fecha de publicación: 02/08/2022
PAG 272-279

Abstract
This article evaluates the physical and mechanical properties of a paving block with added ash from artisanal brick kilns in the city of Juliaca to reduce the environmental pollution generated by the ash. For this purpose, data and test results were collected at the GEOCONTROL laboratory in Juliaca. It was designed for a compressive strength of f'c=340 kg/cm2 for type II pavements, adding ash from artisanal brick kilns of 0%, 5%, 10%, 15% and 20% as a partial replacement of cement. Aggregates from the Cabanillas quarry, Portland cement type I and ash from artisanal brick kilns were used as raw materials for the mixture design. From the results obtained, it is concluded that the addition of 5% ash from artisanal brick kilns improves the compressive strength at 28 days of curing. It is important to mention that if the percentage of added ash from artisanal brick kilns increases above 10%, the resistance decreases. Finally, the dimensional tolerance and absorption of conventional paving blocks and additions of 5% ash from artisanal brick kilns meet the established criteria of NTP 339.611.

Keywords: *Ash from artisanal brick kilns; compressive strength; absorption; dimensioning.*

Resumen
Este artículo evaluó las propiedades físico-mecánicas de un adoquín adicionando cenizas de ladrilleras artesanales de la ciudad de Juliaca, de tal modo se redujo la contaminación ambiental que genera la ceniza, para ello se recolectó datos y resultados de ensayos en el laboratorio GEOCONTROL-Juliaca. Se diseñó para una resistencia a compresión f'c=340 kg/cm2 para pavimentos de tipo II, adicionando cenizas de ladrilleras artesanales de 0%, 5%, 10%, 15% y 20% como reemplazo parcial del cemento, se utilizó como materia prima agregados de la cantera Cabanillas, cemento Portland Tipo I y cenizas de ladrilleras artesanales para el diseño de mezcla. Con los resultados obtenidos se concluye que la adición de 5 % de cenizas de ladrilleras artesanales mejora la resistencia a compresión a los 28 días de curado, también cabe mencionar que conforme se aumenta el porcentaje de adición de cenizas de ladrilleras artesanales después del 10% la resistencia disminuye. Finalmente, la tolerancia dimensional y la absorción de los adoquines convencionales y de los adicionados de 5% de cenizas de ladrilleras artesanales cumple los criterios establecidos de la NTP 339.611.

Palabras clave: Cenizas de ladrilleras artesanales; resistencia a compression; absorción; dimensionamiento.

1. Introduction

The evaluation of compressive strength and absorption of paving blocks is vital because it allows the control of admissible load and quality of the paving blocks for effective performance in pavements in order to meet the requirements of the Peruvian technical standard NTP 399.611 and prevent excessive cracking and deformation of pavements.

Failures commonly found in pavements arise from structural shortages, deficiencies in the construction process, fatigue, and lack of maintenance caused by poor concrete design. Besides, the paving system with traditional paving blocks does not meet the requirements of NTP 399.611 and NTP 399.604 (Lopez and Pinedo, 2015).

The city of Juliaca suffers a huge problem due to the enormous population growth and unpaved streets. In the central parts of the city, the pavements are in extremely poor condition due to erosion, and surface deterioration, among other problems.

The environmental pollution generated by the artisanal brick kilns during brick firing is also identified since tires and different types of plastics are the most commonly used fuel. Therefore, the ash extracted from the artisanal brick kilns is highly pollutant, and it is exposed to the open air in the cities and towns of the Puno region. Also, according to the Regional Clean Air Program, artisanal brick activity is characterized by a high generation of pollutants, a precarious economy, and job insecurity (Condori, 2013).

This research was developed to solve the aforementioned problems of the pavements in Juliaca, improving the physical and mechanical properties of a paving block with the addition of ash from artisanal brick kilns as a substitute for cement, thus considering the appropriate percentage (%) of dosage to resist light vehicular loads, in compliance with the requirements of the Peruvian Technical Standard 399.611, to be subsequently implemented in the pavement system. At the same time, environmental pollution caused by ash from artisanal brick kilns is reduced.

Concrete paving blocks are a replacement option for traditional concrete, as they transfer their distributed loads to the neighboring units. Also, concrete paving blocks serve as a surface water drainage system, which is used in Europe (Palacios, 2016).

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Vol 37 Nº2 2022 www.ricuc.cl
DOI: 10.7764/RIC.00032.21

Ash applied in concrete can develop binding properties when they come into contact with water and Portland cement (Arbelaez, 2020). According to the study named "Influencia de cenizas de ladrillos artesanales en la resistencia a la compresión de adoquines de concreto – Trujillo, 2019" the use of ash from artisanal brick kilns is feasible (Cruz, 2019). In terms of availability, the Province of San Roman has more than 300 artisan brick kilns (Mamani, 2017).

The study of the properties of the fly ash-added mortar called CV, with a high volume of carbon of 19%, showed that the mortars with 10% CV increased their compressive strength by 35% after 28 days of curing. In addition, this mortar stands out for its resistance to the deterioration of the structural material (Burgos et al., 2012). Adding ash from artisanal brick kilns as a substitute for cement in paving blocks increases the compressive strength, exceeding the specifications of NTP 399.611, with a 10% ash substitution for a period of 28 days of curing (Cruz, 2019). Also, the addition of 12% sugar cane ash in type II paving blocks for light traffic increases their compressive strength, and after adding 15% or more, it decreases even lower than the standard. Regarding absorption, the water absorbed will be higher if the portion of ash used is lower (Correa and Polo, 2019).

In Brazil and other countries, paving blocks are used for their aesthetics, permeability during the rainy season, and compressive strength (Montiel, 2017). In Peru, paving blocks are used because of their advantageous compressive strength, aesthetics, durability and easy manufacture (Barrantes and Holguin, 2015).

This research aims to evaluate the physical and mechanical properties of a paving block according to NTP 399.11, adding different dosages of ash from artisan brick kilns to improve the compressive strength and absorption of type II concrete paving blocks for light vehicular traffic load in the city of Juliaca.

For fundamental concepts, the paving blocks are solid prefabricated elements of nominal dimensions or adopted by the manufacturer, which are always of the same thickness since they fit perfectly into the surface during the assembly. This allows an easy and quick installation and low maintenance costs in the future. Type I Portland cement is made from high-quality clinker and gypsum industrially ground to a high degree of fineness. Ash is a by-product obtained from the calcination of artisanal bricks. The aggregate is a mixture of coarse and fine aggregates that form the concrete body. Therefore, the texture, size and shape of the aggregate are highly influential for adequate strength. Water is an essential component for the mixture design, processing, setting and curing of concrete paving blocks.

2. Materials and methods

2.1 *Materials*

2.1.1 Cement, ash, water and aggregates

The cement used in this research is Type I cement with a specific weight of 3.14 gr/cm3, which meets the requirements of NTP 334.009. The ash from Juliaca is applied as follows 0%, 5%, 10%, 15% and 20% with respect to the weight of cement. According to NTP 399.601, other components in the production of concrete paving blocks should be verified not to be harmful through tests or field experience. This research emphasizes the field experience of the study "Influencia de cenizas de ladrillos artesanales en la resistencia a la compresión de adoquines de concreto - Trujillo 2019." Drinking water is used for mixing and curing and meets the requirements of NTP 339.088. The fine and coarse aggregates are from the Cabanillas quarry, according to NTP 400.037, with a maximum size of 3/4", a maximum nominal size of ½" and a fineness modulus of 2.76. The tests performed for the characterization were prepared at the Geocontrol Total E.I.R.L. laboratory and include moisture content, loose and compact unit weights, specific weight, absorption and particle size. The results obtained from each test and their respective standards are shown in (Table 1) (Table 2) and (Table 3) and their corresponding figures, (Figure1); (Figure 2).

***Table 1**. Aggregate Characterization Summary*

Standards and Physical Characteristics		Coarse Aggregate (Gravel)	Fine Aggregate (Sand)
NTP 400.021 and NTP 400.022	S.W. SSS (gr/cm^3)	2.51	2.53
NTP 400.017	U.W. Rod (kg/m^3)	1434	1657
	U.W. Loose (kg/m^3)	1240	1524
NTP 400.021 and NTP 400.022	Absorption % (%)	2.08	2.46
NTP 339.185	Natural Moisture % (%)	1.84	4.68
-	Fineness modulus	-	2.76

Source: Own source based on laboratory tests, 2021

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Table 2. *Average particle size analysis of coarse aggregate*

PASSING PERCENTAGE (%)		
SIEVES		GRAVEL
#	mm	
3"	76.200	
2 1/2"	63.500	100
2"	50.600	100
1 1/2"	38.100	100
1"	25.400	100
3/4"	19.050	100
1/2"	12.700	82.86
3/8"	9.525	32.48
1/4"	6.350	32.48
# 4	4.760	0.44
BOTTOM		

Source: Own source based on laboratory tests, 2021

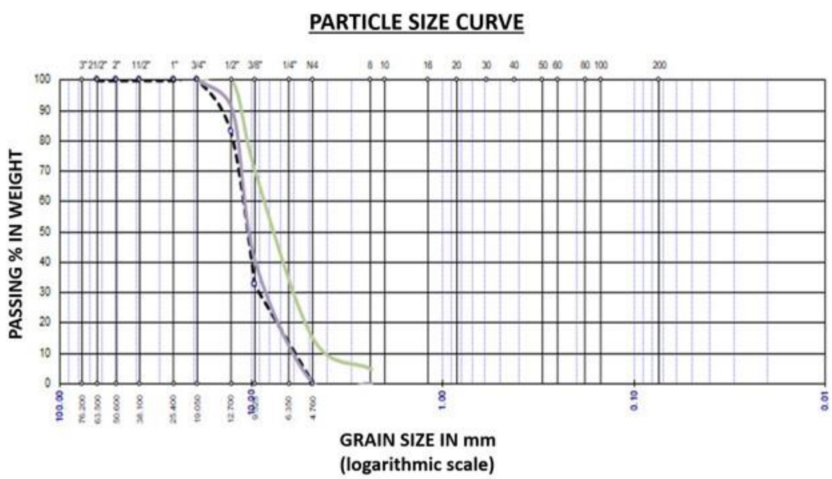

Figure 1. *Graph of coarse aggregate particle size curve*
Source: Own source based on laboratory tests, 2021

Table 3. *Average particle size analysis of fine aggregate*

PASSING PERCENTAGE (%)		
SIEVES		SAND
#	mm	
3/4"	19.050	100.00
3/8"	9.525	100.00
# 4	4.760	95.95
# 8	2.380	80.31
# 16	1.190	67.00
# 30	0.590	51.89
# 50	0.300	24.73
# 100	0.149	4.50
# 200	0.074	1.35
BOTTOM		

Source: Own source based on laboratory tests, 2021

DOI: 10.7764/RIC.00032.21

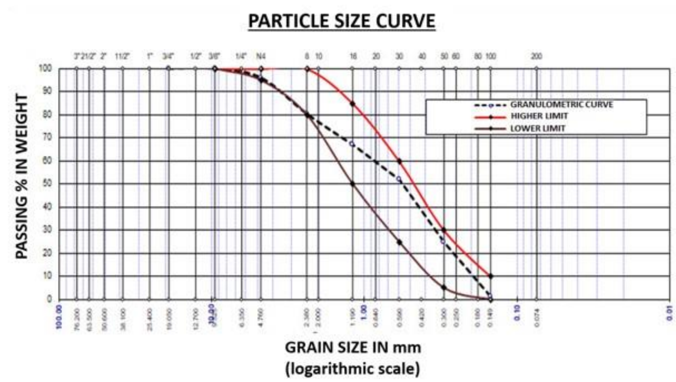

Figure 2. *Graph of fine aggregate particle size curve*
Source: Own source based on laboratory tests, 2021

2.2 Methodology

This is quantitative and experimental research with a correlational scope. Its independent variable is the ash from artisanal brick kilns, and its dependent variable is the compressive strength and absorption of concrete. The population corresponds to all the paving stone specimens evaluated in m3 of concrete and cured in 7, 14 and 28 days, obtained from a dosage with the addition of ash from artisan brick kilns of 0%, 5%, 10%, 15% and 20%, which have been tested for compressive strength and absorption.

The mixture design of the paving blocks was made through the A.C.I. 211 method, which is based on calculating the materials such as gravel, sand, cement and water at volume and weight, for a compressive strength f'c = 340 kg/cm2 and a dry consistency of 1" a 2" for paving, where the dosages for conventional paving blocks were obtained. Then, the dosages with added ash from artisanal brick kilns as a substitute for cement were obtained in percentages of 5%, 10%, 15% and 20% for curing periods of 7, 14 and 28 days.

The designations MP, CP and CL stand for Master Sample, Portland Cement and Ash from Artisanal Brick Kilns, respectively, for easy identification. (Table 4) describes the dosages of the mixture design.

Table 4. *Quantity of materials (dosages) of the mixture design*

MP + Added Brick Ash %	CP (Kg/m^3)	CL (Kg/m^3)	Water (L/m^3)	Fine Aggregate (Kg/m^3)	Coarse Aggregate (Kg/m^3)
MP	523.68	-	184.04	794.21	788.86
MP + 5% C.L.	497.496	26.184	184.04	794.21	788.86
MP + 10% C.L.	471.312	52.368	184.04	794.21	788.86
MP + 15% C.L.	445.128	78.552	184.04	794.21	788.86
MP + 20% C.L.	418.944	104.736	184.04	794.21	788.86

Source: Own source based on laboratory tests, 2021

Physical properties such as absorption and dimensions were evaluated according to NTP 339.611, where the maximum dimensional tolerance in length and width is around 1.6 mm and thickness around 3.2 mm (Figure 3). For the absorption of type II paving blocks, the maximum absorption of a single unit was evaluated as a maximum of 7.5% and, on average, 6%.

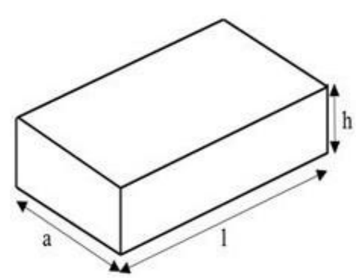

Figure 3. *Length, Width and Thickness of Type II Paving Blocks*
Source: Own source, 2021

DOI: 10.7764/RIC.00032.21

Compressive strength tests were conducted to evaluate the mechanical properties of the concrete paving block with partial replacement of Portland cement, with the objective of evaluating the product of added ash from artisanal brick kilns on the properties of the concrete paving block. (Table 5) shows the description and number of tests.

Table 5. *Number of tests to be evaluated for the mechanical properties of the paving blocks*

MP + Added Brick Ash %	Compressive Strength Test			Absorption Tests
	7 Days	14 Days	28 Days	
MP	6	6	6	6
MP + 5% CL	6	6	6	6
MP + 10% CL	6	6	6	6
MP + 15% CL	6	6	6	6
MP + 20% CL	6	6	6	6
Sub total number of specimens	**30**	**30**	**30**	**30**
Total number of specimens	**120 units**			

Source: Own source, 2021

The compressive strength and absorption tests of the concrete paving blocks were evaluated using rectangular prism-shaped specimens with nominal dimensions of 20x10x8 cm established by NTP 399.611 at the ages of 7, 14 and 28 days of curing, meeting the requirements of NTP 399.604. The load applied to the hydraulic press was automated at a rate of 0.25 MPa/s. (Figure 4)

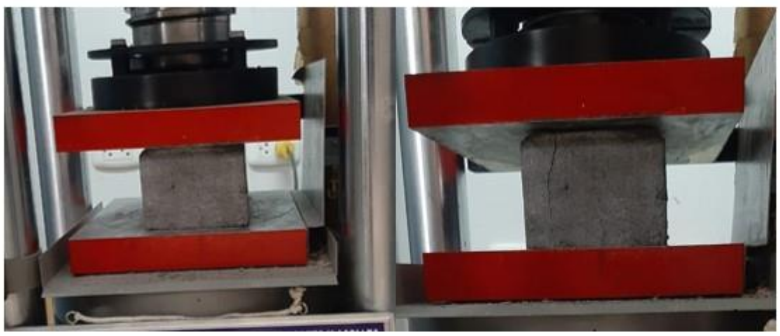

Figure 4. *Compressive strength test and failure*
Source: Own source, 2021

3. Results and analysis

3.1 Physical properties

3.1.1 Dimensioning and longitudinal variation of paving blocks

To check the quality of the paving blocks, tests such as dimensional control are conducted to avoid stresses causing deformations during their useful life. (Table 6) shows the nominal dimensions and the actual dimensions of the paving blocks as length, width and thickness, with the precision of 0.1 mm of each rectangular prism, where an average of 2 measurements was obtained at the edge and in the middle of each face. Measurements were acceptable and met the NTP 399.611 standard.

The variation of the length and width of each paving block is less than 1.6 mm and generally varies by a maximum percentage of 0.41% and 0.77%, respectively, and the variations of the actual dimensions of the thickness of the paving block are less than 3.2 mm, which represents an average maximum variation in percentages of 0.87%.

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Table 6. *Dimensioning and longitudinal variation of paving blocks*

Dosage	Length					Width					Thickness				
	Nominal Dimension (cm)	Actual Dimension (cm)	Variation (mm)	Variation (%)	Average (%)	Nominal Dimension (cm)	Actual Dimension (cm)	Variation (mm)	Variation (%)	Average (%)	Nominal Dimension (cm)	Actual Dimension (cm)	Variation (mm)	Variation (%)	Average (%)
MP	20.00	20.11	1.10	-0.55	-0.32	10.00	10.02	0.20	-0.20	-0.35	8.00	8.04	0.40	-0.50	-0.40
	20.00	20.07	0.70	-0.35		10.00	10.03	0.30	-0.30		8.00	8.06	0.60	-0.75	
	20.00	20.03	0.30	-0.15		10.00	10.03	0.30	-0.30		8.00	8.06	0.60	-0.75	
	20.00	20.02	0.20	-0.10		10.00	10.08	0.80	-0.80		8.00	7.96	-0.40	0.50	
	20.00	20.04	0.40	-0.20		10.00	10.02	0.20	-0.20		8.00	8.08	0.80	-1.00	
	20.00	20.11	1.10	-0.55		10.00	10.03	0.30	-0.30		8.00	7.99	-0.10	0.12	
MP+5% CL	20.00	20.07	0.70	-0.35	-0.41	10.00	10.01	0.10	-0.10	-0.77	8.00	7.99	-0.10	0.12	-0.67
	20.00	20.16	1.60	-0.80		10.00	10.10	1.00	-1.00		8.00	8.06	0.60	-0.75	
	20.00	20.09	0.90	-0.45		10.00	10.10	1.00	-1.00		8.00	8.01	0.10	-0.12	
	20.00	20.03	0.30	-0.15		10.00	10.08	0.80	-0.80		8.00	8.07	0.70	-0.88	
	20.00	20.09	0.90	-0.45		10.00	10.13	1.30	-1.30		8.00	8.13	1.30	-1.63	
	20.00	20.05	0.50	-0.25		10.00	10.04	0.40	-0.40		8.00	8.06	0.60	-0.75	
MP+10% CL	20.00	20.06	0.60	-0.30	-0.37	10.00	10.09	0.90	-0.90	-0.73	8.00	8.08	0.80	-1.00	-0.56
	20.00	20.05	0.50	-0.25		10.00	10.05	0.50	-0.50		8.00	8.02	0.20	-0.25	
	20.00	20.07	0.70	-0.35		10.00	10.11	1.10	-1.10		8.00	8.06	0.60	-0.75	
	20.00	20.12	1.20	-0.60		10.00	10.08	0.80	-0.80		8.00	8.08	0.80	-1.00	
	20.00	20.08	0.80	-0.40		10.00	10.06	0.60	-0.60		8.00	8.02	0.20	-0.25	
	20.00	20.06	0.60	-0.30		10.00	10.05	0.50	-0.50		8.00	8.01	0.10	-0.12	
MP+15% CL	20.00	20.09	0.90	-0.45	-0.37	10.00	10.03	0.30	-0.30	-0.33	8.00	8.08	0.80	-1.00	-0.87
	20.00	20.01	0.10	-0.05		10.00	10.05	0.50	-0.50		8.00	8.08	0.80	-1.00	
	20.00	20.09	0.90	-0.45		10.00	10.00	0.00	0.00		8.00	8.02	0.20	-0.25	
	20.00	20.12	1.20	-0.60		10.00	10.03	0.30	-0.30		8.00	8.09	0.90	-1.13	
	20.00	20.04	0.40	-0.20		10.00	10.08	0.80	-0.80		8.00	8.12	1.20	-1.50	
	20.00	20.09	0.90	-0.45		10.00	10.01	0.10	-0.10		8.00	8.03	0.30	-0.37	
MP+20% CL	20.00	20.02	0.20	-0.10	-0.11	10.00	10.07	0.70	-0.70	-0.40	8.00	8.02	0.20	-0.25	-0.75
	20.00	20.06	0.60	-0.30		10.00	10.02	0.20	-0.20		8.00	8.08	0.80	-1.00	
	20.00	20.03	0.30	-0.15		10.00	10.01	0.10	-0.10		8.00	8.05	0.50	-0.63	
	20.00	20.01	0.10	-0.05		10.00	10.03	0.30	-0.30		8.00	8.08	0.80	-1.00	
	20.00	20.01	0.10	-0.05		10.00	10.02	0.20	-0.20		8.00	8.09	0.90	-1.13	
	20.00	20.00	0.00	0.00		10.00	10.09	0.90	-0.90		8.00	8.04	0.40	-0.50	

Source: Own source based on laboratory tests, 2021

3.1.2 Absorption

(Table 7) shows the average absorption results for different dosages at 0 %, 5 %, 10 %, 15 % and 20 % of ash from artisanal brick kilns.

Table 7. *Absorption results for paving blocks*

Dosage	Absorption (%)
MP	5.07
MP + 5% CL	5.75
MP + 10% CL	7.07
MP + 15% CL	8.57
MP + 20% CL	10.84

Source: Own source based on laboratory tests, 2021

Regarding the absorption of the paving blocks, the standard sample and the addition of 5% ash from artisanal brick kilns are evaluated with a result of 5.07% and 5.75%, respectively, which are within the maximum absorption requirements of NTP 399.611. While, in the 10%, 15% and 20% ash additions, the absorption increases, exceeding the maximum absorption parameters; therefore, they do not meet the standard. (Figure 5)

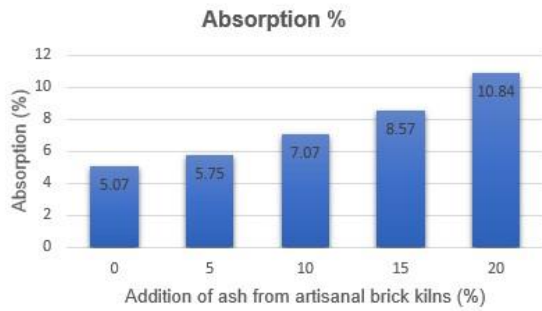

Figure 5. *Absorption graph for different ash dosages*
Source: Own source, 2021

3.2 Mechanical properties

3.2.1 Compressive strength

(Table 8) shows the average results of the compressive strength tests at 7, 14 and 28 days of curing for the different percentage dosages of ash from artisanal brick kilns as a substitute for cement, finding a higher strength for the sample with a 5% substitution, equivalent to an average of 385.69 Kg/cm2. The strength of a paving stone, depending on the percentage of ash from artisanal brick kilns and the number of days of curing, increases and decreases as the ash content increases, i.e., the samples with 10% to 20% ash substitution have a significant decrease in this parameter compared to the standard samples and the design strength; therefore, these substitution percentages are not feasible in the original mixture design.

Table 8. *Absorption and compressive strength results at 7, 14, and 28 days*

MP + Added Brick Ash %	Compressive Strength		
	f'c 7 Days (kg/cm^2)	f'c 14 Days (kg/cm^2)	f'c 28 Days (kg/cm^2)
MP	284.77	316.18	370.04
MP + 5% CL	288.57	326.30	385.69
MP + 10% CL	225.68	255.63	297.58
MP + 15% CL	186.00	210.92	247.39
MP + 20% CL	148.33	161.13	198.12

Source: Own source based on laboratory tests, 2021

(Figure 6) shows that the strength of the paving block increases as the days of curing increase and reaches a considerable strength with an addition of 5% ash from artisanal brick kilns at 28 days of curing. It is important to mention that according to background information, satisfactory strength results were obtained when 10% of ash from artisanal brick kilns was added. However, this research shows that adding 5% favorably increases strength, even exceeding the recommendation of NTP 399.611.

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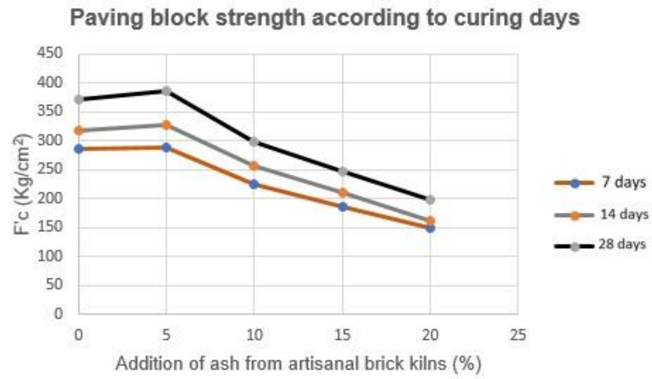

Figure 6. *Compressive strength graph for paving blocks according to curing days*
Source: Own source, 2021

(Figure 6) shows the compressive strength graph of the paving block, the ash from artisanal brick kilns as a replacement in cement percentage is significantly represented in the F'c results. The use of ash as an admixture is a low-cost and useful alternative to improve the mechanical properties of dry or hardened concrete [11]. Accordingly, this study shows once again the beneficial effect of ash on the improvement of the mechanical properties of concrete paving blocks.

4. Conclusions

According to the results of the physical and mechanical tests, the effect of the ash from artisanal brick kilns on a concrete paving block is evaluated, and the results lead to the following conclusions:

The evaluation of paving blocks with the added ash from artisanal brick kilns in percentages of 0%, 5%, 10%, 15% and 20% influences the strength and absorption of concrete, where at 28 days of curing for an addition of 5% ash from artisanal brick kilns it reaches a strength above a conventional paving block, while with the addition of 10% or more, the strength of the paving block decreases considerably.

Notably, the ash from artisanal brick kilns improves the mechanical properties of concrete paving blocks. Their use helps mitigate environmental pollution. Also, the partial replacement of up to 5% of cement provides better workability and reduces production costs. Finally, in terms of the absorption of conventional paving blocks and those with the addition of 5% ash from artisanal brick kilns, they meet the criteria established in NTP 339.611, which explains the increase in strength of 4.2% compared to the standard sample at 28 days, but also the addition percentages of 10% or more ash do not meet the maximum absorption.

This demonstrates that the higher the absorption exceeding the recommendations of the standard and other influential factors, the lower the strength.

For future studies, an evaluation of the physical and mechanical properties of the paving blocks for percentages within the range of 0% to 10% of added ash from artisanal brick kilns is recommended, as well as an analysis of the chemical composition of the ash.

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