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Use of construction and demolition waste for the production of paving stones for pedestrian walkways

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Abstract
The main problem of our cities is the lack of treatment and final disposal of construction and demolition waste (CDW), which, accompanied by a lack of knowledge, becomes a major problem. Likewise, a city in the north of Peru (Cutervo) is not immune to the problematic reality experienced in the country and worldwide, since the lack of CDW management projects has generated the formation of informal dumps. The main objective of this research is to determine the technical and economic feasibility of using CDW for the production of pedestrian pavers, given that it includes measurements of the physical and mechanical characteristics to be analyzed. It is concluded that the use of CDW in the production of paving stones is feasible, from the economic and technical aspects, incurring a reduction in cost.

Keywords: pedestrian pavers; concrete; recycled aggregate; mix design; compressive strength; construction and demolition waste.

Aprovechamiento de residuos de construcción y demolición para la elaboración de adoquines peatonales

Resumen
El principal problema de nuestras ciudades es la falta de tratamiento y disposición final de los residuos de construcción y demolición (RCD), que acompañados de falta de conocimiento se convierten en un problema mayor. Asimismo, una ciudad al norte del Perú (Cutervo) no es ajena a la realidad problemática que se vive en el país y a nivel mundial, ya que, la falta de proyectos de gestión de RCD ha generado la formación de botaderos informales. Esta investigación, tiene como objetivo principal determinar la factibilidad técnica y económica de la utilización de RCD para la elaboración de adoquines peatonales, dado que comprende mediciones de las características físicas y mecánicas a analizar. Se concluyó que es factible el uso de RCD en la elaboración de adoquines, desde el aspecto económico y técnico, incurriendo en una disminución del costo.

Palabras clave: adoquín; concreto; agregado reciclado; diseño de mezcla; resistencia a la compresión; residuo de construcción y demolición.

1. Introduction

Globally, construction is considered a sector of greater relevance and importance that positively influences the social and economic growth of a country. However, there is also a significant population growth that leads to the accelerated execution of public and private works buildings to satisfy needs. Given the execution of these projects, the generation of solid waste and construction and demolition waste occurs that must be anticipated to be managed appropriately to mitigate these negative effects on human health and the environment.

Currently, there is a reality of negative environmental impact due to the overexploitation of natural resources to satisfy various needs of the population, which leads to this action generating great global concern, thus considering it necessary to promote and encourage recycling activities. reuse of materials and/or waste to generate positive impact on our environment [1].

The main objective of the Waste Law of Peru is to reduce environmental pollution rates, encouraging the reduction of the use of plastic containers for biodegradable containers. [2]. Likewise, the European Union constitutes a legal framework

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for the proper processing of waste, presenting as its main objective the preservation of our environment and the health of appropriate management, restoration and recycling of waste.

In the world, there is an environmental problem, therefore, the need arises to intercede in the issues of recycling waste such as plastics, rubber tires and other waste, as it is considered a matter that affects the environment. In Bogotá, it is considered necessary to find optimal and appropriate solutions to supply, reuse and recycle materials and/or products to achieve sustainable development [3].

We can deduce that there is a knowledge gap related to the correct management of waste, as there is a lack of information for the management of this waste, which is represented by people's ignorance and lack of information on the part of the authorities towards the citizens to carry out good practices for the benefit of our environment, which is why this research was carried out to be able to make better use of RCD in the production of concrete pedestrian pavers.

1.1 Construction in the national and local context.

In Lima, approximately 19 thousand tons of debris is collected throughout the day and 70% goes directly to rivers and seas, so only a small portion goes directly to areas authorized as formal dumps, the rest ends up contaminating soils and rivers [4]. According to the Peruvian Chamber of Construction (CAPECO), the city of Lima produces around 30,000 m3 of landfill.

The main problem in our cities is the lack of treatment and final disposal of construction and demolition waste, which, together with a lack of knowledge, becomes a major problem. In addition, the poor or non-existent management of these wastes by the municipalities results in the spread of open-air dumps, contaminating the environment and becoming infectious sources that can even cause damage to health.

The city of Cutervo is no stranger to the problematic reality of the country and the world, since the lack of solid waste and construction and demolition waste management projects has led to the formation of informal dumps, which has a major negative impact on environmental contamination. However, the fact that Cutervo is a rainy area has not been taken into account, which generates the dragging of waste into rivers and streams, contaminating and affecting them considerably.

This city presents a good momentum of growth and development in the civil construction sector, thus generating an increase in the execution of projects that leads to a parallel increase of debris as construction and demolition waste (CDW). To mitigate this problem related to our environment in the locality, the initiative was born to carry out the present proposal focused on evaluating the technical and economic feasibility of the use of these CDW in the elaboration of concrete pedestrian pavers.

Thus, the objective of this research was to determine the technical and economic feasibility of using construction and demolition waste to make concrete pedestrian pavers in the city of Cutervo.

1.2 Paving blocks and their characterization

1.2.1 Definition

These are blocks elaborated in different shapes and sizes, the most used material for their elaboration has been granite, because it provides great resistance, although at present they are being manufactured with different materials [5]. This has an enormous advantage over other materials, thanks to its ease of transport and placement, it is used in avenues, parking lots, gardens, among other urbanization works. For its placement, a trench must be made according to the thickness of the paving stone, then a layer of gravel (small stones) with a thickness of 10 to 15 centimeters must be added, followed by a layer of fine sand with a thickness of 2 centimeters.

Paving stones are classified according to the use required. Table 1 shows these types, whether for pedestrian or vehicular use [6].

Table 1.
Types of paving stones

Type	Use	Thickness (mm)
I	Pedestrian	40 60
II	Light vehicles	60 80
III	Heavy vehicles	≥ 80 100

Source: Ministry of Housing, Construction and Sanitation [6].

1.2.2 Physical properties of paving stones

Dimensions

These can vary, especially due to the thickness of the pavers, as well as the use and load capacity of the pavers. According to [6], Peruvian Technical Standard (NTP) 399.611 establishes three types of pavers, type one for pedestrian traffic use, type 2 for light vehicular traffic use and type 3 for heavy vehicular traffic use.

Weight

The weight will always be conditioned to the different dimensions and materials of which the paving stone is composed [6].

Texture

The paving stone has multiple ways of being placed in the pavement, since it has different textures, among them are smooth, flamed, bush-hammered, aggregate, among others [6].

1.2.3 Mechanical properties of paving stones.

Compressive strength

This is the procedure where tests are carried out based on NTP 339.611, where the capacity to support a weight load is tested. [7].

Resistance to abrasion

This test measures the resistance to wear caused by constant pedestrian traffic and is closely related to the compressive strength. [7].

Resistance to freezing and thawing

According to [7], it is a phenomenon of freezing and thawing of the water found in the pores of concrete, this is usually one of the most destructive agents of concrete, since it involves and affects both the mix and the aggregates.

1.3 Construction and demolition waste

1.3.1 Definition

Construction and demolition waste, also known by its acronym CDW, is waste from construction, repairs or demolition, whether of buildings or infrastructure [8]. These can be classified according to their origin, since various types of waste can be found. Among them excavation waste (sand, gravel, earth, etc.), construction and maintenance of works (asphalt, metals, etc.) and demolition (concrete blocks, plaster, brick, etc.)

1.3.2 Composition

These are made up of several components, among the main ones are concrete and ceramics, and it is also necessary to take into account where they come from, based on that we can know the composition of each waste [8]. We have three types of waste, which are made up in different ways: Construction waste is 75% made up of rubble and ceramics which are from cuttings and broken materials, while demolition waste is made up of various materials such as synthetic fibers, metals, plastics, ceramics, plasters, plasters, etc. These tend to be more contaminated than RC. On the other hand, earth extraction waste is clean, stony waste of variable nature.

1.3.3 Benefits of CDW recycling

By not becoming aware of CDW, we would be contributing in a negative way to the current problems that all countries present with respect to pollution. Given this, Cevallos [9]. tells us that the recycling of this waste appears to be an incredible option to reduce the impact it has on the environment, which is why new alternatives for using RCD are being presented. This is why recycling could bring the following benefits: reduction in management costs and expenses related to cleaning due to the inappropriate dumping of this waste around the entire city, low rate in the extraction of natural raw materials such as gravel and sand, Reduction in pollution, especially in the soil and the air.

2. Methodology

Applied research is the one in charge of applying existing theories and knowledge in order to obtain a possible solution to a problem [10]. Thus, this research is considered to be applied research, since the application of various Peruvian technical regulations and theoretical contributions related to pavers and their feasibility through the incorporation of construction and demolition waste (CDW) was carried out in order to generate a positive effect on their behavior as a material and thus become a viable alternative in various future projects.

Also, a quantitative approach research is one that is responsible for the collection of measurable and quantifiable information, i.e., it is based on the validation of its hypothesis under a numerical scale [11]. Therefore, this research was considered to have a quantitative approach, since it carried out a quantitative evaluation of the characteristics and properties of the study samples, in this case, the pavers with the incorporation of construction and demolition waste (CDW), in order to represent their mechanical properties, costs, among other important indicators under a numerical support.

The explanatory level is a level of research that deals with the measurement of two or more study variables, which are detailed and characterized to determine their condition or purpose of study [12]. In view of the above, this research is considered a proposal with an explanatory level, as it is focused on providing a detailed characterization of the behavior of pavers with the incorporation of a waste material.

Finally, in terms of design, an experimental design is that type of research focused on manipulating the independent variable to generate a cause-effect relationship on the dependent variable [13]. Thus, this thesis research was considered with an experimental design, being in charge of handling construction and demolition waste (CDW) in specific percentages or dosages with the purpose of generating a variation in the behavior of concrete pavers, thus obtaining its cause-effect of this construction material before the incorporation of a waste material.

2.1 Population, study sample and sampling

A population is a group of elements or objects that present similar characteristics, however, due to its large size and extension it cannot be considered for a study as a whole [14]. Thus, this research considers construction and demolition waste from various informal landfills outside the city of Cutervo as the study population.

A study sample is considered to be that subset of elements or objects with specific and desired characteristics for a study with the purpose of representing a general population [10]. This research considered as a study sample the construction and demolition waste coming from 02 landfills specifically in the city of Cutervo located on the Cutervo-Sócota and Cutervo-Chipuluc roads. Regarding the study sample considered for the evaluation of the mechanical behavior (compressive strength) of the pavers, it is necessary to detail the quantities of specimens used for this study in table 2.

Table 2.
Study sample for compressive strength

Samples	**Age**		
	7 Days	**14 Days**	**28 Days**
Pattern paver sample	3	3	3
Sample of paving stone with 30% RCD	3	3	3
Sample of paving stone with 50% RCD	3	3	3
Sample of paving stone with 70% RCD	3	3	3
Sub-total samples	12	12	12
Total samples	36 paving stone units		

Source: Own elaboration, 2023.

Table 3.
Study sample for water absorption

Samples	Quantity
Pattern paver sample	3
Sample of paving stone with 30% RCD	3
Sample of paving stone with 50% RCD	3
Sample of paving stone with 70% RCD	3
Total samples	12

Source: Own elaboration, 2023.

While, for the evaluation of physical behavior, specifically for the water absorption test, Table 3 considers the following study sample.

Table 4.
Grain size analysis of recycled coarse aggregate

Sieves ASTM	Opening (mm)	Retained weight	Partial Retained	Retained Accumulated	Percent passing	Specifications Grava Huso 7	
3/4"	19.000				100.00	100	100
1/2"	12.700	1,328.0	13.90	13.90	86.20	90	100
3/8"	9.520	3,798.0	39.60	53.50	46.50	40	70
1/4"	6.350	2,364.9	24.70	78.10	21.90		
N° 4	4.750	2,094.0	21.85	99.99	0.01	0	15
N° 6	4.750			99.99	0.01		
N° 8	2.360			99.99	0.01	0	5
N° 10	2.000			99.99	0.01		
N° 16	1.190			99.99	0.01		
N° 20	0.850			99.99	0.01		
N° 30	0.600			99.99	0.01		
N° 40	0.420			99.99	0.01		
N° 50	0.300			99.99	0.01		
N° 60	0.250			99.99	0.01		
N° 80	0.180			99.99	0.01		
N° 100	0.150			99.99	0.01		
N° 200	0.074			99.99	0.01		
Pasante		0.1	0.00	99.99	0.01		

Source: Own elaboration, 2023.

3. Results

3.1 Physical and mechanical characteristics of construction and demolition wastes

In the present investigation, the material obtained from construction and demolition waste was part of the coarse aggregate; likewise, the fine aggregate used for the preparation of the mix design was obtained from the "El Verde" quarry, located in the city of Cutervo. The following are the results obtained from the various tests that made it possible to determine the physical and mechanical characteristics of the aggregates.

Coarse aggregate (construction and demolition waste)

The characteristics of the coarse aggregate were obtained through the application of four laboratory tests. Among these are: Granulometric Analysis, Unit Weight, Specific Gravity and Moisture Content, which are described below.

Granulometric analysis

This analysis was performed following the International Standard ASTM D-422, C-117, to determine the particle size distribution of the coarse aggregate, where the total initial weight of the sample was 9.585 kg, with maximum particle size equal to ¾", as well as maximum nominal size of ½". Table 4 shows the percentage of coarse aggregate that passes the various sieves considered for this test.

Fig. 1 shows that the granulometric curve of the recycled coarse aggregate presents a tendency towards the lower limit of Spindle 07, with a slight overflow in the ½" sieve, given that the lower limit has as a value of percentage passing by weight equal to 90%, unlike the sample under study, with 86.20%. However, the distribution that follows is positioned within the limits of this spindle.

With respect to the Atterberg limits, the results obtained for this sample showed that it does not present a liquid, plastic limit and, therefore, a plasticity index. Likewise, when classifying this material, it was possible to identify the soil as poorly graded gravel (GP), according to SUCS classification and as an A-1-a (0) soil, according to AASHTO classification.

- **Unit weight**

The ASTM C-29 International Standard was used to determine the average moisture content, loose unit weight and compacted unit weight. The results of this test showed void contents of 2.3% and 2.4% for the samples, with an average value of 2.33%. In addition, the loose unit weights obtained from the samples under analysis were 1.324, 1.330 and 1.331kg/cm3, with an average value of 1.328kg/cm3. Finally, the samples tested to determine the compacted unit weight presented values of 1,511, 1,512 and 1,515kg/cm3, with an average value of 1,513 kg/cm3. These results are shown in Table 5 in greater detail.

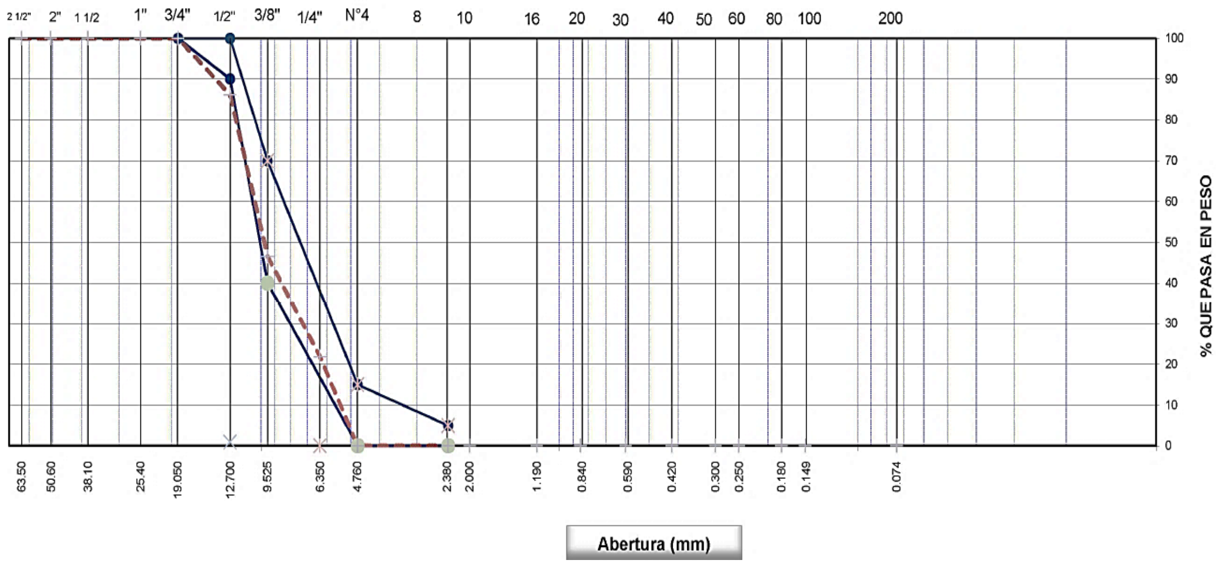

Figure 1. Recycled coarse aggregate particle-size curve
Source: Own elaboration, 2023.

Table 5.
Recycled Coarse Aggregate Unit Weight Test Results

Description	M1	M2	M3	Average
Void content	2.30%	2.40%		2.33%
Dry loose unit weight	1.324 kg/cm3	1.33 kg/cm3	1.331 kg/cm3	1.328 kg/cm3
Dry compacted unit weight	1.511 kg/cm3	1.512 kg/cm3	1.515 kg/cm3	1.513 kg/cm3

Source: Own elaboration, 2023.

Fine Aggregate

- **Granulometric análisis**

It can be seen in Fig. 2 that the granulometric curve of the fine aggregate presents a trend in the central zone of the limits of the Reference Zone provided in the ASTM C-33 Standard, with a slight overflow in the 3/8" sieve, since the lower limit has a value of percentage passing in weight equal to 95%, unlike the sample under study, with 99.17%. However, the distribution that follows is positioned within the limits of this spindle.

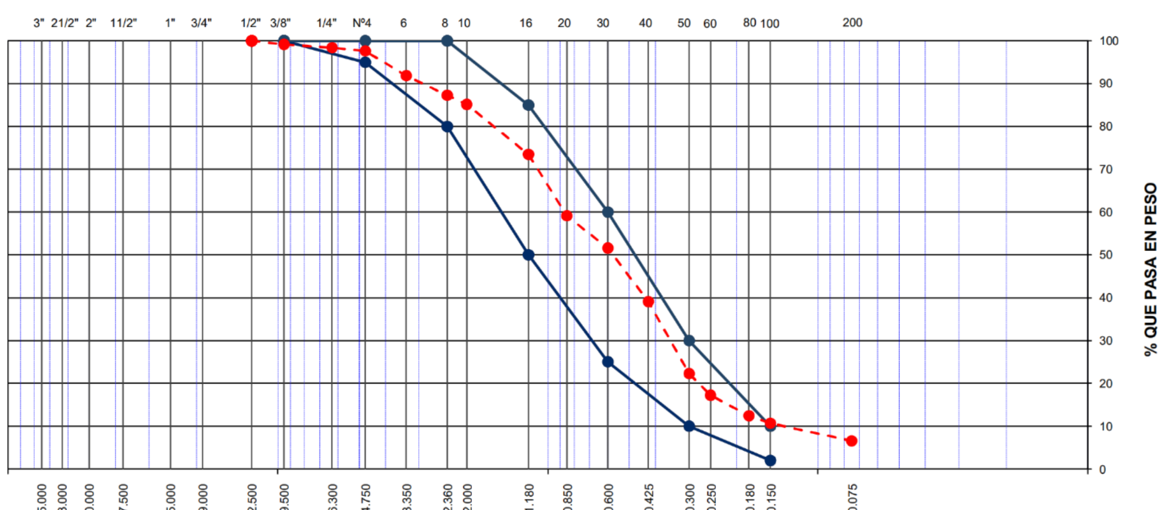

Figure 2. Granulometric curve of fine aggregate
Source: Own elaboration, 2023.

3.2 Concrete mix design for paving blocks

In the development of this research, it was determined to carry out a mix design for a concrete of resistance equal to f'c=290kg/cm2, by means of the A.C.I. Method, in order to obtain a concrete paver suitable for pedestrian use. It should be added that a standard sample was initially made, which will undergo variations according to the proportions of recycled coarse aggregate proposed, which are 0%, 30%, 50% and 70%. The general considerations for the mix design include a slump of 2 ± 1 ½", according to ASTM C-94ª, a cement factor of 10.41 bls/m3 and a water cement ratio of 0.45. Below in Tables 6 and 7, the results obtained for the preparation of the concrete mix design are shown.

To carry out the dosage of the materials, the physical and mechanical characteristics obtained from the aggregates under study were used, where the fine aggregate was obtained from the "El Verde" quarry and the coarse aggregate comprises construction and demolition waste. The dosage in weight presents a ratio of 1.00: 2.01 : 1.85 : 0.32, according to the mix design, where the weight of the fine aggregate per m3 of concrete is 890.00 kg, as well as the weight of the coarse aggregate, with a value of 816.02 kg. With respect to the proportion in volume, the ratio was 1.00 : 1.74 : 1.98 : 13.77, for one bag of cement.

Table 6.
Dosage by weight for concrete f'c=290kg/cm2

Cement	442.22	Kg/m3.
Water	142.86	l/m3.
Fine Aggregate	890.00	Kg/m3.
Coarse Aggregate	816.02	Kg/m3.

Source: Own elaboration, 2023.

Table 7.
Dosage in volume for concrete f'c=290kg/cm2

Cement	1.00	Bolsa (pie3)
Fine Aggregate	1.74	Pie3 por bolsa
Coarse Aggregate	1.98	Pie3 por bolsa
Water	13.77	Litros por bolsa

Source: Own elaboration, 2023.

Table 8.
Summary of resistances obtained in compressive strength tests.

Date of Manufacture	Age (days)	Resistance
Design 290 kg/cm2 with 0 % recycled material (pattern)	-	
	7.00	214.37
	14.00	263.40
	28.00	322.10
Design 290 kg/cm2 with 30 % recycled material	-	
	7.00	231.60
	14.00	265.90
	28.00	319.23
Design 290 kg/cm2 with 50 % recycled material	-	
	7.00	212.86
	14.00	267.51
	28.00	308.58
Design 290 kg/cm2 with 70 % recycled material	-	
	7.00	190.76
	14.00	244.61
	28.00	295.52

Source: Own elaboration, 2023.

From table 8 we see that the first mix design carried out was with 0% recycled material, whose samples were manufactured on 05/03/2022, with a total of 9 samples, which had a breakage date of 05/10/2022 for the 7-day samples. curing, 05/17/2022 for samples with 14 days of curing and 05/31/2022 for samples with 28 days of curing. The resistance results obtained were 214.37 kg/cm2 on average for the samples at 7 days of curing, 263.40 kg/cm2 on average for the samples at 14 days of curing and 322.10 kg/cm2 on average for the samples at 28 days of curing.

For the production of the paver with 0%, 30%, 50% and 70% of RCD, the costs are those shown in Fig. 3. It should be added that the total costs obtained for each alternative do not include the cost of the General Tax on the sale (IGV).

4. Discussion

Regarding the results obtained, the optimal percentage of RCD was 30%, unlike other percentages, where the resistance decreases with respect to the standard mix design, without construction and demolition waste. Likewise, when analyzing the economic aspect, an inverse trend was observed in relation to the cost and percentage of RCD, such that, the higher the percentage of RCD, the unit cost of paving stone decreases. That said, the economic and technical feasibility of using RCD in the production of pavers is demonstrated.

Cuenca y Sepúlveda [15] The results obtained were compressive strengths at 28 days of curing equal to 130.87 kg/cm2, where the most common type of failure was type 5. When comparing these results with the present investigation, a considerable increase in the resistances obtained is observed at 28 days, where the minimum value was 391.15 kg/cm2 with a percentage of 70% of RCD, and with predominant type 1 failure.

Regarding the optimal percentage of construction and demolition waste, Kelly y Esteban [16] they concluded in their research that this value is 50%, with which they obtain compressive strength of 41MPa, equivalent to 418.1 kg/cm2; However, it does not exceed the standard sample, which has a resistance of 45MPa. In contrast to the present investigation, where the optimal percentage of RCD was 30%, whose resistance manages to be minimally below the value obtained in the standard sample. It should be added that the resistance obtained was much lower compared to the reference research, given that the maximum resistance was 319.23 kg/cm^2.

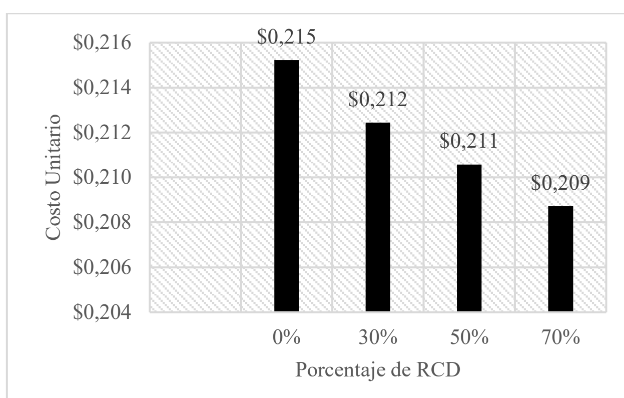

Figure 3. Percent recycled vs unit cost in dollars.
Source: Own elaboration, 2023.

5. Conclusions

Construction and demolition waste was obtained from two landfills located on the outskirts of the city of Cutervo. According to the criteria of location, safety, amount of material and accessibility, the best option to obtain the waste was determined, obtaining Dump 02 as the favored option, with a score of 6.6, compared to 8.7 for Dump 01. Therefore, it was concluded that obtaining the material would be from Dump 02.

The coarse aggregate that was replaced by construction and demolition waste through adequate segregation for the production of concrete pedestrian pavers in the city of Cutervo were characterized in order to identify its physical properties, thus determining a moisture content of 1.77%, loose unit weight of 1,376 kg/cm^3, compacted unit weight of 1,512 kg/cm^3, an apparent weight of 2,654 gr/cc and an absorption percentage of 0.43%. Likewise, regarding their granulometry, these coarse aggregates were identified that did not present plasticity, being classified as a GP material according to SUCS and according to AASHTO as an A-1-a (0) material, in its entirety, it had a content of 92.3 % gravel, 12.9% sand and 0.6% fines.

Compression tests were carried out on concrete pavers with 0%, 30%, 50% and 70% aggregates under the guidelines of NTP 399.611, which reached an average resistance of 214.37 kg/cm^2 after 7 days. 231.60 kg/cm^2, 212.86 kg/cm^2 and 190.76 kg/cm^2, respectively. While, after 14 days, values of 263.40 kg/cm^2, 265.90 kg/cm^2, 267.51 kg/cm^2 and 244.61 kg/cm^2 were obtained for each study sample. Finally, after 28 days, these samples obtained average compressive strengths of 322.10 kg/cm^2, 319.23 kg/cm^2, 308.58 kg/cm^2 and 295.52 kg/cm^2, respectively.

The concrete pedestrian paver with replacement of coarse aggregate by construction and demolition waste (RCD) presents unfavorable mechanical characteristics, having obtained compressive strengths at 28 days of 319.23 kg/cm^2 for the paver sample with 30% RCD, while, the paver sample with 50% RCD reached a resistance of 308.58 kg/cm^2, and the paver sample with 70% RCD obtained an average resistance of 395.52 kg/cm^2, compared to the standard sample with a value of 322.10 kg /cm^2.

The influence of the addition of construction and demolition waste on the mechanical properties of pedestrian pavers is not favorable with the replacement of 30%, 50% and 70% RCD, since the reduction in its compressive strength was evident in 2.87 kg/cm^2, 13.52 kg/cm^2 and 26.58 kg/cm2 compared to the pattern paver sample. However, the concrete paver with the replacement of coarse aggregate with 30% RCD achieves a lower influence by reducing 2.87 kg/cm2, despite not being significant, it is relevant, since it becomes a sustainable alternative allowing to obtain resistances. similar to the standard sample. With this we avoid the depletion of natural resources such as coarse aggregate through the use of waste, which will not need to end up in informal dumps that do not undergo any treatment and generate greater environmental pollution, but would be used for the production of eco-friendly pavers.

Given the proposed general objective, the use of construction and demolition waste for the production of concrete pedestrian pavers in the city of Cutervo becomes an optimal alternative of sustainable material for construction, presenting a positive technical and economic feasibility, given that the unit price of the optimal RCD percentage option (30%) was $0.215, in contrast to the standard sample option, with a cost of $0.212. In addition, it is considered an eco-friendly proposal for our environment by reducing negative impacts on our environment, not only with the use of solid construction and demolition waste but also by avoiding the depletion of natural resources such as aggregates.

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