

# MANUFACTURE OF PERFORATED CONCRETE MASONRY UNITS USING TAILINGS FROM AGGREGATE MINING.

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**Abstract:** This research project proposes the use of mining aggregates tailings, in the elaboration of units of perforated concrete masonry as a percentage replacement of the cement, evaluating the physical behavior of 4 mix designs with different percentages of replacement. The project consists of 4 methodological phases that contemplate the physicochemical characterization of the tailings, the design of mixtures, the analysis of the mechanical behavior of the mixtures with tailings replacement through tests of compressive strength and water absorption, and an economic analysis that defines the percentage of savings represented by each replacement of cement per tailings in the total cost of the block.

In general, and in accordance with the results of the tests carried out, the 4 mixtures designs with replacements showed a good mechanical performance, reaching in most cases more than 90% of the resistance of the standard design and decreasing by up to 34% the percentage of water absorption of the blocks, besides representing a saving up to 41% in the cost of production per block.

**Keywords:** Environmental impact, mining, structural masonry unit, tailings.

## 1. INTRODUCTION.

Mining in Colombia has its origin in the Spanish conquest period, which began the activities of silver and gold mining in the sixteenth century and continued in its exploitation for 3 centuries through rudimentary methods with slave labor, tools of iron and black powder, until the end of the 18th century, when the technology of the mines in the hands of German engineers began, beginning the modernization of sinkhole and alluvial mines. Precious minerals were the only products exploited until the beginning of the 20th century when oil was first produced and then non-metallic minerals for industrial use such as sulfur, limestone, clays, quartz, gypsum and others.[1]

Currently, mining activities in recent years, have reflected great importance in the Colombian economy, representing 6.05% of GDP and 54% of the country's exports for 2017, according to figures given by the National Administrative Department of DANE statistics [2]. However, despite its economic importance, the damage caused to the ecosystems of the surrounding areas not only at the time of extraction of the mineral, but also the waste (tailings) generated after this process, tend to be irreparable.

The waste originated from the exploitation of natural resources and industrial activities, have caused an increase in pollution rates around the world, caused by an eagerness in man to find solutions that mitigate and counteract the impact generated in the environment.

In this sense, the alternatives proposed to a greater extent, are focused on giving a use or application to the pollutant residues that accumulate, as a total or partial substitute of the raw material used in the manufacture of construction materials.

Sectors such as agroindustrial, for example, have developed research on the manufacture of perforated ceramic blocks, of equal dimensions to conventional blocks, by means of a replacement in different percentages of clay content, by sludge from the treatment plants of wastewater (WWTP). These blocks, after completing their stages of preparation and cooking (at 1200 ° C for 72 hours in a Hoffman oven), were analyzed and compared to a reference block without replacement (100% clay) by compression tests, absorption and flexion. The results obtained by the tests carried out were that the dosage with which the

ceramic brick would have better mechanical characteristics is with a 10% replacement, which not only complies with the current Colombian technical regulations, but also would reduce by 10% production costs of conventional blocks.[3]

In this case, we have also come up with many investigations around the world about the use of the different types of waste generated by the processes of mineral exploitation, in the elaboration of construction materials.

Students from the civil engineering department of the Sethu Institute of Technology, Kariapatti, Tamil Nadu-India, for example, evaluated the properties of green concrete made from wastes of quarry rock and marble as substitutes for 100% of the fine aggregate of concrete, with in order to reduce the consumption of natural resources and its environmental footprint. To do this, two concrete mixtures were analyzed: one with conventional materials (cement, sand and water), and another with sand replacements with 50% quarry rock dust and 50% marble dust. [4]

The mixtures were subjected to slump, slump flow, V-funnel time tests to verify their workability before being melted and tests of compressive strength, tensile strength, water absorption and resistance to the attack of sulfates at curing ages of 3, 7 and 28 days. It was demonstrated that the use of the aforementioned wastes significantly improves the mechanical properties of concrete due to its chemical composition resembling that of cement (material with pozzolanic character), and its efficient micro-filling capacity that reduces voids in concrete, as It is usually difficult to find well-graded sands in this area. Superior resistance to compression and tension was demonstrated with values of 40.35 N / mm<sup>2</sup> and 5.02 N / mm<sup>2</sup> respectively, in comparison with the conventional concrete that has resistances of 36.85 N / mm<sup>2</sup> and 4.62 N / mm<sup>2</sup>, as well as its workability favoring its self-compacting behavior, It also has lower permeability and greater resistance to sulfate attacks. [4]

Likewise, the residual sludge generated by mining activities known as tailings, are also used in the construction materials processing processes. In the Sandur region, Karnataka - India, a study was carried out to manufacture blocks of compressed earth and tailings from iron mining, as an alternative solution to the accumulation of waste from a dam that represents a risk of breakage at rainy season, located in a mining area.[5] For manufacturing, the iron mining waste was dosed at 30, 40 and 50%, the cement was mixed with silts at 8 and 10% and the remaining percentage was completed with marble powder. [5]

According to the tests of compression and flexural strength and water absorption carried out at the ages of 7, 15, 30, 60 and 180 days, it was found that the resistance to compression increases over time and that the best performance occurred in compliance with the specifications of the standard is the corresponding to 40% replacement of iron mining tailings, 10% of cement and silt and 50% of quarry dust. Water absorption rates around 30 days are less than 15% as required by the standard and all the dosages that were used have optimal bending strength values to withstand stresses during construction, as well as structural loads. [5]

In South Africa, students of chemical and metallurgical engineering at the University of the Witwatersrand, Johannesburg analyzed the feasibility of manufacturing blocks with gold mining tailings from the Witwatersrand watershed; given that, being one of the main economic activities in the area, its overexploitation generates huge amounts of mining tailings that affect the environment.[6]

The analysis was carried out using the tailings as a total replacement of the fine aggregate, using eight mixtures with different proportions of cement, tailings and water. Once manufactured, they were subjected to three different curing methods: sun-dried, in an oven at a temperature of 360°C and cured in water for 24

hours. Once this phase was finished, the compression strength and water absorption tests were started. The results showed that, in general, the blocks have greater resistance to compression when they are cured in water, since it favors the chemical reaction of the cement; It was also found that the mixture that obtained the best performance was the 2: 1 cement tailings dosing with a resistance of 530 KN / m<sup>2</sup>. Considering that the average compressive strength of conventional blocks is 750 Kn / m<sup>2</sup>, it was determined that, although it is possible to manufacture blocks from mining tailings, it does not improve its structural behavior and represents a higher cost since it requires more cement content. [6]

In the case of Peru, one of its investigations on the subject, made by students of the César Vallejo University, is related to the mixing of the mining tailings of the district of Ticapampa, along with pozzolanic material and sawdust for the elaboration of ceramic cobblestones.

The methodology used consisted of making an identification of the physicochemical parameters of the materials to be used, finding high contents of lead and iron sulfide in the tailings used, so that before the elaboration of the ceramic cobblestones, it was necessary to go through a stage of neutralization of heavy metals, using lime as an alkaline material in a percentage of 0.8 for each type of mixture. Once the neutralization and characterization stages were completed, the cobble elaboration process was started, which was divided into different material concentration tests, within which, in addition, a process of molding, pressing and burning of the block was developed. Its mechanical characteristics were tested by tests of compressive strength, moisture content and water absorption. Once the tests were finished and analyzed, it was determined that the dosage with which the cobblestones would present a better performance compared to the conventional model was 0.80% lime, 40% cement, 5% clay, 28.56% sawdust, 0.64% granulated quartz and 25 % tailings. [7]

Similarly, students of the Pontifical Catholic University of Peru, made as a research proposal the incorporation of 3 tailings samples from different mining sites in the country, in concrete mixtures as volumetric filler or as an additive pozzolanic. However, the results of the characterization of the materials ruled out the use of the tailings as a volumetric filler due to its fineness (Fineness Module of 0.60), which would imply the use of a greater amount of additive (medium-range water reducer). Polyheed 770R ") to get a workable mixture. In addition, said material presented a large amount of sulphates in its composition, which, although it is within the limits allowed by the Peruvian Technical Standard, could cause potential problems of durability in the concrete. [8]

Having said the above, the methodology for the use of the tailings as a pozzolanic additive was then started with the design and preparation of concrete mixtures, both of the master mix (using the ACI method), and those with cement replacements in an order of 10% and 15% of tailings; then evaluating the compression strength at 3, 7 and 28 days, and the traction by diametral compression and abrasion after 28 days of curing. Subsequently, thanks to the good results obtained in the mechanical tests at an early age for one of the 3 samples of tailings used (Andaychagua), mixtures were made with 20% and 25% replacements with this tailings, in the same curing times. [8]

Once analyzed the results given by the tests in each mixture, it was determined as the best performance mixture to the GA-ANDAY (10%), which is a design with replacement of 10% cement by weight for the Andaychagua tailings. It was then concluded based on the results that the best use for the concrete mix proposed was in the construction of pavements with light transits or paths, without discarding however (with a wider study) its use in the elaboration of different types of prefabricated low resistance. [8]

In Brazil, in the state of Minas Gerais, there is a place called the Ferrero quadrilateral because of the many companies that are dedicated to the exploitation of iron; which leave about 700 tailings deposits of fine

granulometry, representing an environmental passive in the extraction zone. The aforementioned, took students of master's degree in construction materials engineering from the Federal Center for Technological Education of Minas Gerais to carry out a study on the reuse of waste from iron mining deposits for paving of roads and the manufacture of cobblestones [9]

To do this, cobbles were made with a standard mixture commercially used by industry and three mixtures replacing 10, 50 and 80% of the fine aggregate, and were cured in the open air by controlling the temperature with water. The tests carried out of DRX, FRX, tomography, compression strength, mineralogical analysis and water absorption, showed that the pavers containing the tailings are able to withstand heavy traffic efforts, complying fully with the minimum resistance required by the standard Brazilian technique (35Mpa) with about 50 Mpa of resistance and presenting a behavior similar to the blocks made with the master mix. According to the tests, the blocks also have a lower porosity, which translates to a longer useful life of the pavement, the expansion index increases and the water absorption decreases.[9]

In the case of the use of tailings for the paving of roads, through CBR analysis, it was found that it can be implemented in the subbase, however, it is not advisable to implement it in the base (layer that supports and distributes efforts to the subsoil), since it does not meet CBR specifications. However, although it was shown that the tailings can be used in the preparation of paving stones and pavement layers, the high moisture content in the deposits from which the tailings are extracted, means that the material must be subjected to sun drying processes, macerated and sifted before being used, which represents more efforts and time for companies. [9]

On the other hand, in the case of the reuse of mining tailings in the preparation of concrete blocks, the National University of Huancavelica in Peru, in its investigation "Use of the mine tailings for the production of concrete blocks assemblable type" proposed to elaborate blocks of concrete with a design resistance of 14.71 Mpa, reusing the mining tailings with replacements of 25%, 50%, 75% and 100% of the fine aggregate. To do this, in the first phase they underwent tests of compression strength and water absorption after 28 days of curing, 7 cylindrical test tubes for each type of mixture. According to the results of the mentioned tests, it was observed that the mixture design that showed the highest strength to compression (14.15 Mpa) was that with 50% replacement. Said mixture would be the one used then in the elaboration of the assemblable blocks, which after the 28 days of curing again were subjected to strength and absorption tests, resulting in a strength of 7.79 MPa and an absorption of 11.54%. [10]

The investigation concluded, according to the analysis of the results provided, that the use of the mine tailings as a substitute for the fine aggregate in the concrete mix is a viable solution, since it has mechanical characteristics that are within the limits established by Peruvian technical regulations. , besides generating a saving compared to conventional materials of 7.85% in construction costs per square meter of wall. The authors also suggest advancing research that incorporates the mix design proposed in the development of paving stones, concrete sidewalks and low traffic pavements.[10]

Similarly, again in India, a country that has large reserves of iron and is one of the main producers worldwide, exploiting more than 2,500 million tons per year; an investigation was made by students of mining engineering of the Indian Institute of Technology of Kharagpur, proposing experimentally the use of IOW (iron ore waste) in the development of blocks as a substitute for sand and cement, in order to save resources and generate sustainable development. [11]

In the development of the research, they submitted 4 concrete mixtures with different percentages of IOW, cement and sand to tests of compressive strength and water absorption at 7, 14, 21 and 28 days of curing. As a result, it was concluded that the mixture made of cement, sand and IOW, with a dosage of 30:30:40 after 28 days of curing, has a compressive strength of 42.95 MPa and water absorption of 2.42%, complying

with the standards and specifications of the Bureau of Indian Standards IS-2180: 1988 (minimum compressive strength of 40 MPa and a water absorption percentage of less than 10%) for heavy-duty blocks, used in bridges and foundations, and also representing a high energy saving by not requiring cooking during the production process. [11]

## 2. METHODOLOGICAL DEVELOPMENT.

The experimental phase of this project was divided into 4 stages, which range from the physical-chemical characterization of the materials, to the corresponding mechanical and economic analysis of the results of the tests carried out; each of these stages being described in detail below.

### 2.1 Obtaining the material and physicochemical characterization.

#### 2.1.1 Obtaining the material.

The mine tailings used in this investigation was obtained from the Tailings dam of the Zafiro plant, located at Km 18 of the village El cocuy in Villavicencio-Meta, Colombia; dedicated to the extraction and crushing of drag materials in the Guayuriba River, for the production of gravel, sand, bases and sub-bases, among other construction materials.

#### 2.1.2 Chemical characterization.

X-ray fluorescence (XRF) is a technique that can be used to determine the chemical composition of a wide variety of sample types (including solids, liquids, sludges, and loose powders), by means of a semiquantitative analysis non-destructive [12].

In the case of this investigation, the results of the trial, as evidenced in Table I, revealed that the tailings have a high composition of silicon and aluminum, representing about 79% of the total chemical composition of the sample.

TABLE I  
CHEMICAL COMPOSITION OF THE TAILINGS (RESULTS FRX ESSAY).

NAME	ELEMENT AND / OR COMPOUND	XRF (%IN WEIGH)
Silicon	SiO <sub>2</sub>	65.31%
Aluminum	Al <sub>2</sub> O <sub>3</sub>	13.64%
Iron	Fe <sub>2</sub> O <sub>3</sub>	5.73%
Potassium	K <sub>2</sub> O	2.39%
Sodium	Na <sub>2</sub> O	0.91%
Magnesium	MgO	0.86%
Titanium	TiO <sub>2</sub>	0.65%
Sulfur	SO <sub>3</sub>	0.45%
Calcium	CaO	0.32%
Match	P <sub>2</sub> O <sub>5</sub>	0.17%
Manganese	MnO	0.08%
Barium	Ba	0.06%
Zirconium	Zr	0.04%
Chrome	Cr	0.03%
Cerium	Ce	0.02%
Rubidium	Rb	0.01%

Source: Authors.

### 2.1.3 Physical characterization.

- **Granulometry of the tailings.**

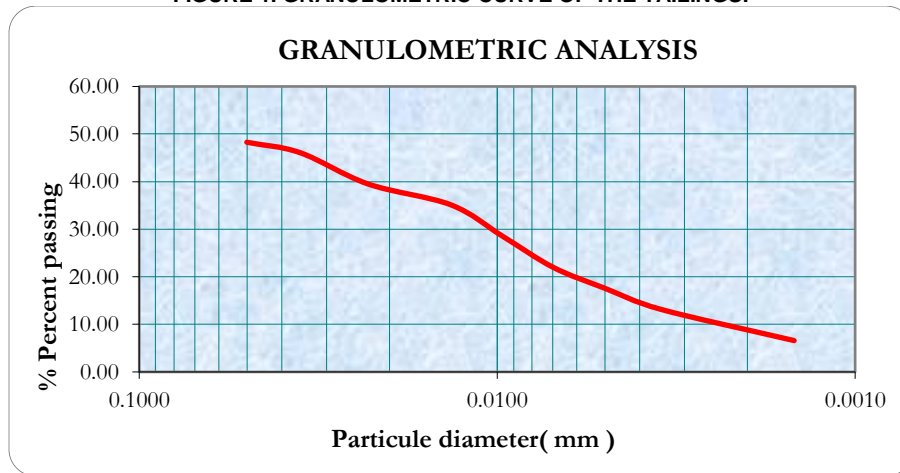
In order to determine the size and distribution of the tailings to be used, a granulometric analysis was carried out using the hydrometer method, in accordance with the INVIAS-E-123-13 standard. As a result, it was concluded once the test ended, that the particles of the sample had a 50  $\mu\text{m}$  diameter in greater average, as shown in Table II.

**TABLE II  
GRANULOMETRIC ANALYSIS OF THE TAILINGS BY HYDROMETER.**

Time (min)	Hydrometer reading (R)	% Percent passing	Particule diameter D (mm)
1	27	48.274	0.0501
2	26	46.079	0.0355
5	23	39.497	0.0229
15	21	35.108	0.0135
30	18	28.525	0.0097
60	15	21.943	0.0070
120	13	17.554	0.0050
250	11	13.166	0.0035
1440	8	6.583	0.0015

Source: Authors.

**FIGURE 1. GRANULOMETRIC CURVE OF THE TAILINGS.**



Source: Authors.

- **Specific weight of the tailings and sand.**

The specific weight of the solids for this investigation was determined under the INVIAS-128-13 standard for the case of tailings, and the INVIAS-E-222-13 standard for the case of sand. The results obtained at the end of the tests of each material, can be seen in Table III.

**TABLE III  
SPECIFIC WEIGHT OF TAILINGS AND SAND.**

	TAILINGS	SAND
Specific weight (gr/cm <sup>3</sup> )	2.46	2.72

Source: Authors.

- **Tail consistency limits.**

The consistency limits tests were carried out on a tailings sample of approximately 200 grams according to the INVIAS-E-125-13 and INVIAS-E-126-13 standards; which resulted in a liquid limit of 26.32%, a plastic limit of 17.98% and a plasticity index equal to 8.35%, as shown in Table IV.

**TABLE VI  
CONSISTENCY LIMITS OF THE TAILINGS.**

LÍMITES DE CONSISTENCIA.		
Liquid Limit	L.L	26.32%
Plastic Limit	L.P	17.98%
Placticity Index	I.P	8.35%
Degree of consistency	Kw	1.01
Degree of consistency	Half hard, solid.	

Source: Authors.

## 2.2 Design of mixtures and elaboration of the blocks.

In this stage, the pattern mix design was made taking as a reference the dosage (1: 5) and water cement ratio (w / c: 0.5) used commercially by regional prefabricated companies, and 4 designs with percentage replacements of 10%, 20%, 30% and 50% cement per tail in the mixture, as presented in table V.

It should be mentioned that the quantities of materials (sand and cement) in the master mix were adjusted according to their absolute volumes.

**TABLE V  
AMOUNT OF MATERIALS REQUIRED FOR EACH MIXING DESIGN.**

Mixing design **Material.	Pattern.	Replacement 10% (R10)	Replacement 20% (R20)	Replacement 30% (R30)	* Replacement 50% (R50)
<b>Cement (Kg)</b>	11.61	10.45	9.29	8.12	3.87
<b>Sand (Kg)</b>	58.03	58.03	58.03	58.03	38.69
<b>***Water (Kg)</b>	5.80	5.22	4.64	4.06	3.87
<b>w/c</b>	0.5	0.5	0.5	0.5	0.5
<b>Tailings (Kg)</b>		1.16	2.32	3.48	3.87

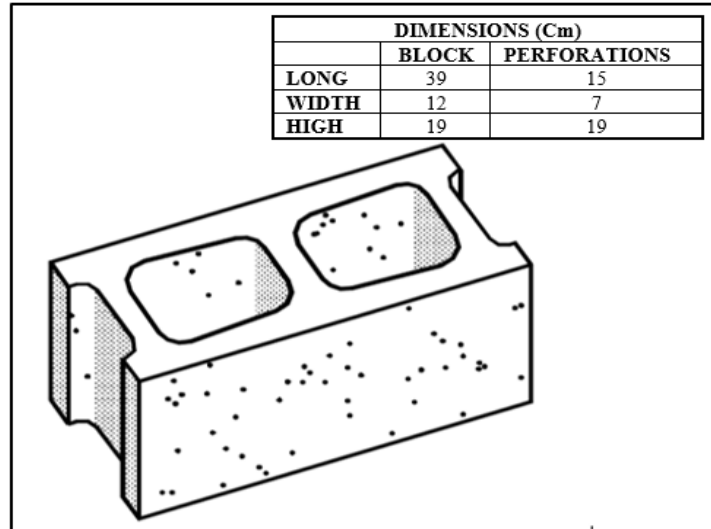
**NOTES:**

- \* The quantities of each material are given for the elaboration of 6 concrete blocks H-12 (see figure 2) for each mix design, with the exception of the R50 design, whose calculations were adjusted to make only 4 blocks H-12
- \*\* The given quantities of each material, already contemplate within the calculations for each design 5% of waste.
- \*\*\* An adjustment of the amount of water was made for each mixing design, in order to maintain a water / cement ratio (w / c) of 0.5 in all cases.

Source: Authors.

Finally, once the design of the mixtures was completed, the elaboration phase of the H-12 blocks (whose dimensions can be seen in Figure 2) was started, using a vibro-compaction machine during the process.

**FIGURE 2. DIMENSIONS OF THE CONCRETE BLOCK H-12.**



Source: Adapted and modified from [13].

Once all the blocks have been prepared and the setting process is finished, the specimens are immersed in a curing tank until the day they are subjected to the compression strength and water absorption test.

### **2.3 Resistance strength and water absorption tests.**

The tests of compressive strength and water absorption for each design were carried out under the norm NTC-4024 and NTC 4026 at 7,14 and 28 days of curing. The blocks corresponding to the R50 mixture were only tested at 14 and 28 days.

In the case of this investigation, the strength of the blocks will be evaluated according to the limits and requirements for low resistance structural use concrete blocks given by the NTC-4026 standard.

**FIGURE 3. COMPRESSION STRENGTH TEST SCHEME FOR CONCRETE BLOCKS.**



Source: Authors.

### 2.3.1 Compressive strength test.

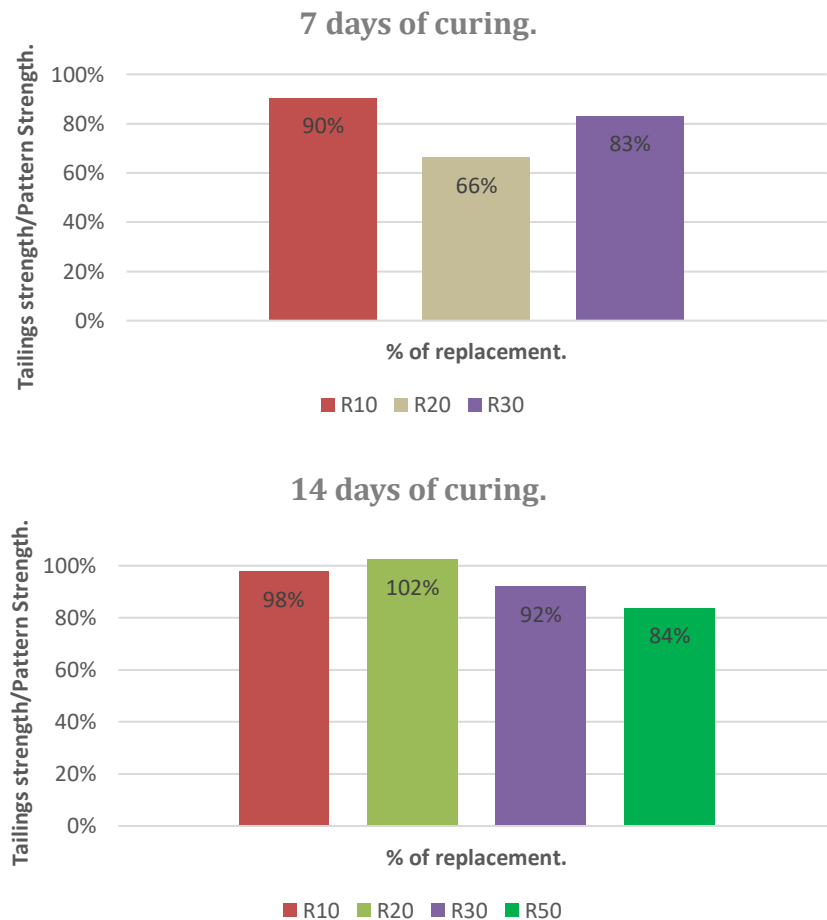
In the tests of strength at 7 days of curing, the mixture R10 reached near 90% of the strength of the master mix, presenting the best behavior of the 3 mixtures with replacement; followed by the mixture R30 and R20 with a percentage of 83% and 66% respectively, as shown in Figure 4.

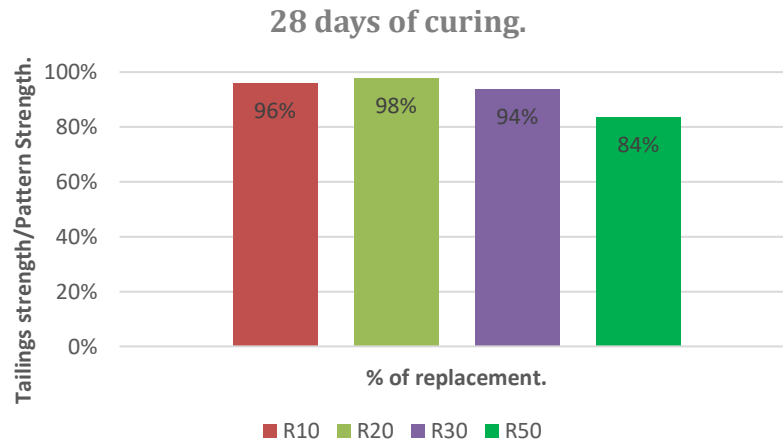
On the other hand, given the good performance presented by the mixtures with replacement versus the standard design at early ages, it was decided to make a new mix design with a 50% replacement of the cement per tailings, evaluating its compressive strength and percentage of water absorption by means of mechanical tests at 14 and 28 days of curing, in order to have a referent of its mechanical behavior in both early and late ages.

Said the previous thing, at 14 days of curing of the blocks with replacement presented again a good mechanical performance in front of the reference mixture, standing out the performance of the mix R20, reaching a 102% of the resistance of the master mix; followed by the mixture R10, R20 and R50 with a percentage of 98%, 92% and 84% respectively.

Finally, after 28 days of curing, again the design that showed the best performance in relation to the master mix was the R20 mixture, reaching 98% of its resistance; followed by the mixture R10, R30, R50 with a percentage of 96%, 94% and 84% respectively.

**FIGURE 4. COMPRESSIVE STRENGTH OF THE MIXES WITH REPLACEMENT IN RELATION TO THE STRENGTH OF THE PATTERN MIXTURE AT 7, 14 AND 28 DAYS OF CURING.**



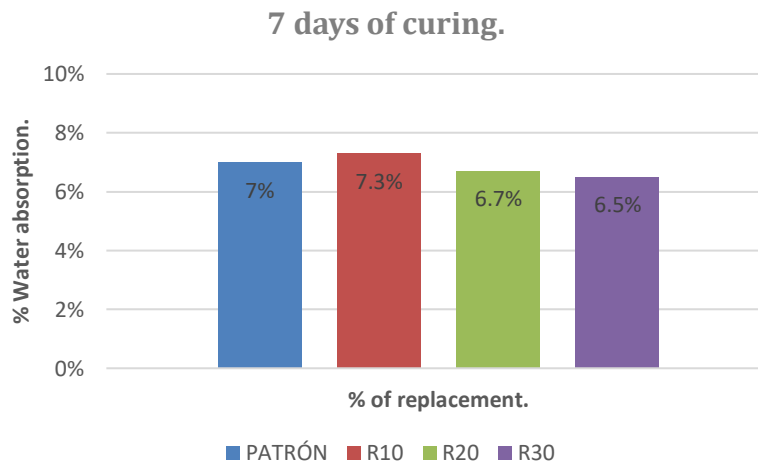


*Source: Authors.*

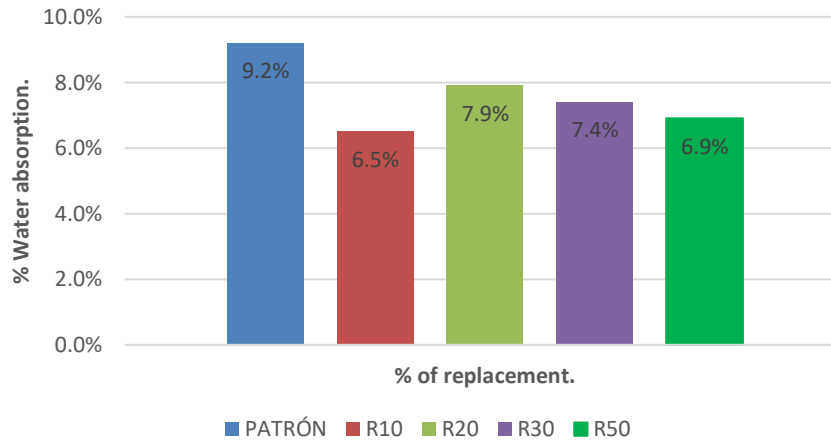
### 2.3.2 Water absorption.

In the case of the water absorption test, in all ages of curing, the results presented a range of difference of less than 5% between the percentages of absorption of the mixtures with replacement and the standard mixture; suffering slight increases (in all cases) of the absorption percentage between 7 and 28 days of curing, as evidenced in figure 5.

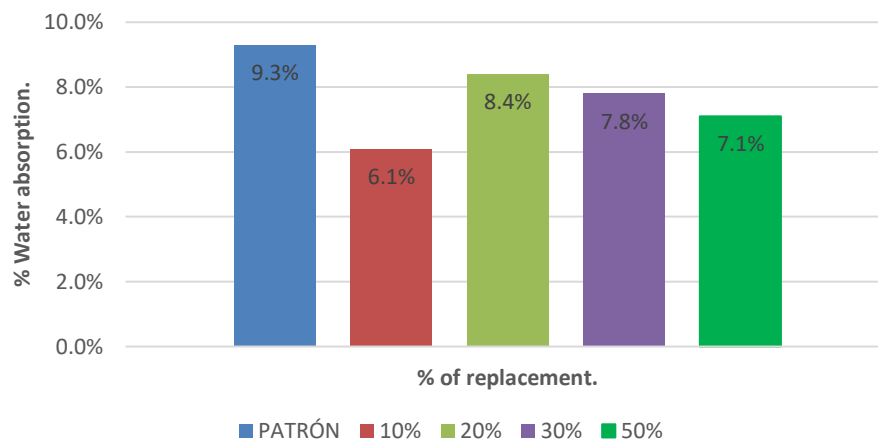
**FIGURE 5. PERCENTAGE OF WATER ABSORPTION OF THE BLOCKS AT 7, 14 AND 28 DAYS OF CURING.**



### 14 days of curing.



### 28 days of curing.



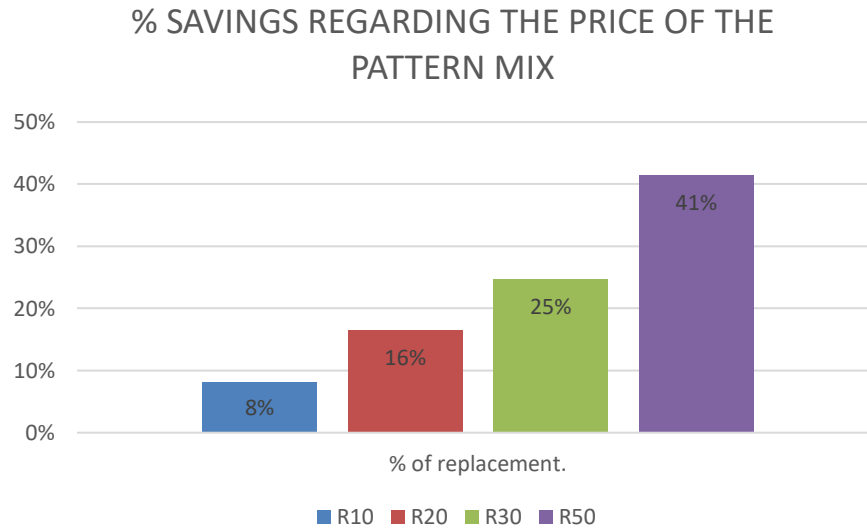
Source: Authors.

## 2.4 Economic analysis of the project.

Initially, a comparison of production per unit of masonry was proposed between the master mix and that mixture that would have presented the best mechanical performance according to the tests carried out, in order to determine its economic viability. However, given the good performance of the blocks with replacements throughout the tests, it was decided to make this comparison with each of the mix designs, determining in addition to their economic viability, the percentage of savings that each replacement would represent to the total cost of production per unit of masonry (See figure 6).

On the other hand, the prices given in this analysis for sand and cement are the product of quotes made to different shops in the city, in order to have a real estimate of the cost of production of each unit of masonry. In the case of the tailings, only the transport price per cubic meter was considered from the El Zafiro plant to the urban perimeter of Villavicencio, given that since it was a waste material, it did not represent any commercial value.

**FIGURE 6. PERCENTAGE OF SAVINGS OF THE TOTAL COST OF PRODUCTION PER UNIT OF MASONRY OF THE MIXES WITH REPLACEMENT WITH RESPECT TO THE PATTERN MIX**



*Source: Authors.*

### **3. ANALYSIS OF RESULTS.**

#### **3.1 Physicochemical characterization.**

The tailings used is a waste material, fine and low plasticity, product of the crushing process, screening and classification of the drag material extracted from the Guayuriba river by the El Zafiro crushing plant; with a particle size similar to that of clay loam soils, according to the granulometric classification given by the INVIAS-123-13 standard and the results given by the consistency limits tests (see tables II and IV).

On the other hand, its chemical composition, high in oxides of silica, aluminum and iron (see table I), makes it a pozzolanic material, with the capacity to form (in the presence of moisture) compounds that have cementing properties, in accordance with the Colombian technical standard NTC-385.

#### **3.2 Mix design.**

Since the objective of the research is to analyze the incidence of the tailings in the strength of the concrete mixtures, the adjustment in the amount of water of each mixture will be determined, in order that the water cement ratio is equal in all the cases, and that is not an influential factor in the difference of mechanical behavior present in the mix designs.

#### **3.3 Tests of compressive strength and water absorption.**

In general terms, according to the results given by the water absorption test in the 3 ages of curing, it can be inferred that the use of the tailings as a percentage replacement of cement in concrete mixtures does not negatively affect the percentage of absorption of the blocks, even in high replacement percentages, as is the case of the R30 and R50 mixes.

Regarding the replacement-resistance relationship, according to [14] it is considered that the loss of resistance of the mixtures with replacement versus the pattern design should be proportional to the amount of cement replacement, for example a mixture with 90% cement, 10% less strength is present. However, the performances in relation to the standard design at all the replacement levels in the 3 ages of curing, had

a percentage of loss of resistance lower than their replacement percentages, which indicates positive impacts of the percentage use of the tailings in the concrete mixtures from the perspective of mechanical strength.

The above can be attributed to the fineness (under diametral size) of the tailings, which provides a more uniform, homogeneous mixture without considerable porosity, this due to its ability to accommodate the particles, which in terms of resistance is favorable.

On the other hand, it is pointed out that the variation in the resistance of the R20 mixture against the tendency given by the other mixtures with replacement, is attributed mainly to human errors committed during the process of elaboration of the block.

### **3.4 Economic analysis of the project.**

The analysis of the project showed favorable results in all the replacement percentages (figure 6) with significant savings of up to 41% in the total cost of production per unit of masonry, as is the case of the R50 mixture; also taking into account that the results given during the mechanical tests in all the replacement cases, were always within the limits and ranges allowed for this type of blocks according to the norm NTC 4026. The previous thing, converts the project then into a highly competitive commercial alternative.

## **4. CONCLUSIONS**

According to the results of the mechanical tests carried out, the R20 mixture was the one with which the best performance was achieved both at early and late ages in relation to the standard mixture, reaching 98% of its resistance at 28 days of curing, as evidenced in figure 4. However, taking into account the economic analysis carried out, it is concluded that the optimal mixture of this research is the R50 mixture, since it not only meets the mechanical requirements given by the NTC 4026 norm, but also (as seen in Figure 6) generates savings of up to 41% in the total cost of production per unit of masonry. Significant data that converts the proposal of this project into a highly commercially viable alternative.

In addition to the above, and considering that the cement industry generates around 5% of the CO<sub>2</sub> emissions generated by man worldwide [15], it becomes the implementation of the tailings of aggregate mining as a replacement for cement, in large percentages, an alternative not only commercially competitive, but also of great impact on the environment.

On the other hand, the range of uses of the blocks proposed in this document is wide, both structural and non-structural, given that the standard NTC 4026 establishes that masonry units that comply with the requirements and limits established by this standard, may also be used to make non-structural masonry.

Given the pozzolanic character of the tailings, it is also recommended to carry out new mechanical tests after 90 days of curing, in order to determine more broadly the performance of the mixtures with replacement at later ages.

In addition to the above, it is advisable to submit the blocks to tests that verify the durability of the material and its behavior when exposed to weathering agents for a long time.

Likewise, given the results of the resistance of the blocks in high replacement contents, it would be worth experimenting experimentally with mixtures with gradual increments of replacement (above R50), in order to find the highest percentage of replacement with which the mechanical characteristics of the masonry unit remain within the limits established by standards 4026 and 4076.

Similarly, it is expected that the results of this study, serve as a basis for future research on the use of this waste in the development of other materials such as tiles, curbs and pavers, or for the implementation in projects of construction of social housing.

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