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Influence of rubber particles on the compressive strength of concrete blocks

Edison Javier Lara Guerrero, David Patricio Guerrero Cuasapaz, Byron Iván Altamirano León

Universidad Politécnica Salesiana, Facultad de Ingeniería Civil, Av. Rumichaca Ñan y Av. Moran Valverde, Casilla 17-12-536, Quito-Ecuador

*Autor de correspondencia: dguerrero@ups.edu.ec

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Abstract

The problem in the disposal of rubber particles, creates a necessity to propose new alternatives to approach the mitigation of the environmental impact generated by the contamination of tires. In this sense, taking advantage of this recycled material is proposed for use in construction materials. This investigation consists in the design and elaboration of a prototype concrete block using rubber particles, for different percentages of substitutions by fine aggregate that has similar technical and economic characteristics of a conventional type B concrete block, proposed in the standard NTE INEN 3066 2016-11. The proposal is the replacement of percentages (10%, 15% and 20%) in volume of fine aggregates by rubber particles product of the crushing of tire. The results show that the alternative is viable under the parameters mentioned above; therefore, the concrete block with 20% rubber particles showed a minimum net compression strength of 3.69 MPa complying with the established. The price of the prototype concrete block with 20% rubber particles is cheaper than a conventional block type B proposed in this research.

Keywords: prototype block; recycled rubber; concrete; compression resistance.

Influencia de las partículas de caucho en la resistencia a la compresión de bloques de concreto

Resumen

La problemática en la disposición de residuos de caucho crea la necesidad de proponer nuevas alternativas, el enfoque es la mitigación del impacto ambiental generado por la contaminación de los neumáticos, aprovechando este material reciclado se propone la utilización en materiales para la construcción. La investigación consiste en el diseño y elaboración de un bloque de concreto prototipo utilizando partículas de caucho, para diferentes porcentajes de sustitución por agregado fino, que posea similares características técnicas y económicas de un bloque de concreto convencional tipo B, propuesto en la norma NTE INEN 3066 2016-11. Lo propuesto, es la sustitución de porcentajes (10%, 15% y 20%) en volumen de agregado fino por partículas de caucho producto de la trituración de neumático. Los resultados exponen que la alternativa es viable bajo los parámetros antes mencionados; por lo tanto, el bloque de concreto con partículas de caucho del 20% de sustitución mostró una resistencia neta mínima a la compresión simple 3,69 MPa cumpliendo con lo establecido. El precio del bloque de concreto prototipo con partículas de caucho del 20% de sustitución resulta más económico que un bloque convencional tipo B propuesto en esta investigación.

Palabras Clave: bloque prototipo; caucho reciclado; concreto; resistencia a la compresión.

Introduction

The increase in the population generates a greater demand for housing in both the rural and urban sectors, thus also generating a demand for construction materials.

The different construction techniques that exist are developed from the significant need to take advantage of the elements that surround us. This need is remarked, for example, by the environmental impact of vehicle tires. For this reason, in recent years we have observed how construction professionals include certain elements in construction materials.

The number of vehicles circulating increases year by year. Thus, we see the generation of by-products from vehicles, such is the case of waste that comes from mechanical processes of tire retreading [1].

The environmental problem of tire waste is generated by the lack of knowledge of waste management plans, due to both cultural issues and the lack of government policies that intervene in private companies, and a lack of research on the reuse and final disposal of this type of waste.

In Ecuador, given the absence of the enforcement of political measures that indicate what to do with tires that are no longer useful for driving, the Ministry of Environment of Ecuador (MAE, in Spanish) launched the Integrated Used Tire Management Plan, in order to reduce the environmental pollution caused by this product. The 1998 Ministerial Agreement, which in its relevant part provides that tire dealers must recover 30% of their market.

The State considers tires as a special waste, because their combustion produces toxic clouds and can also be a source for the spread of epidemics transmitted by mosquitoes [2].

Due to this, it becomes necessary to generate ideas that allow solutions for this type of problem, including the use of rubber particles from crushed tires in concrete blocks, thus minimizing the environmental impact and increasing profits by the production of these items.

In the research carried out by Torres [3], "It was concluded that mechanical strength (compression) was reduced with the three volume percentages of added rubber waste. The mechanical properties of concrete were assessed by changing the volume of the fine aggregate with tire rubber waste by 10%, 20% and 30%."

On the other hand, in the research carried out by Bastidas P. and Viñán M. [4], "The compressive strength reached at 28 days in the concrete mixes, in relation to the size of rubber particles that pass through sieves No. 16, No. 30 and No. 50 were 69.95%, 82.65% and 80.36% related to the conventional concrete mix that obtained 100% compressive strength, which was the original design objective for the mix. Therefore, the mix that had the best performance was the concrete made with particles retained in sieve No. 30". It should be mentioned that we quote this research here to take advantage of the results obtained from the particles where the best strength was obtained.

The research by Nazer A. et al. [1] indicates that "in the compression and flexo-traction tests, it was found that the control concrete mix showed the best compression behavior at 28 days"; it also states: that the feasibility of manufacturing concrete that has adequate compressive strength is evident with the inclusion of various types of fibers, among which are the tire particles that are out of use.

In order to analyze the influence of the addition of granulated rubber from disused tires, as part of the fine aggregate in the manufacture of concrete hollow blocks, through destructive and non-destructive tests, the research indicates that the addition of up to 20% of rubber does not present significant variations when compared to traditional concrete. On the other hand, the dynamic stiffness modulus decreases with a greater addition of granulated rubber, and the granulated rubber in concrete offers greater acoustic and thermal insulation [5].

Another clear example is the recovery of runway rubber particles that result of the tire friction on the taxiing surface, as a modifying material for an asphalt mix that uses AC-20 asphalt [6].

There is good compatibility between the particles of out of use tires and concrete, and also there is an "improvement with respect to cracking by retraction and dissipation of elastic energy, which would result in a reduction in the noise level of traffic" [7], which is an area of research used in the design of concrete road surfaces or foundations using rubber fibers.

This research article was prepared with the purpose of analyzing and evaluating the incidence of replacing fine aggregates with rubber particles from recycled tires and determining the results that will be influential in environmental and economic aspects.

Experimental

The research was carried out in the city of Quito, province of Pichincha, Ecuador. The rubber particles used for this work were collected in Durallanta in the south of the city. The analysis of the physical properties of the particles were carried out in the Materials Testing Laboratory of the Salesian Polytechnic University.

Three types of concrete mixes were made with rubber particle sizes retained in the sieves (see Table

1) and a conventional mix (minimum net compressive strength in concrete blocks type B - average minimum net strength = 4.0-3.5 MPa).

Table 1. Sieves used in the sieving of rubber.

ASTM Sieve (#)	Particle size (mm)
4	4.760
8	2.380
10	2.000
12	1.700
16	1.190
30	0.596

Material characterization

Cement.

The cement used is the ARMADURO® brand, Type IP (general use) ASTM C 595, with a density of 3.1 g/cm^{3,} in accordance with the NTE INEN 490 standard, with a specific weight of 2.92 g/cm^3 [8]

Water.

Drinking water at room temperature (13 °C - 23 °C) was used for the mix.

Aggregates.

Stone materials from the Pifo quarry, in province of Pichincha, observing NTE INEN 696 standard (ASTM C 136-06) were used. [9]

Granulometry.

The granulometry of the fine and coarse aggregates was performed under the NTE INEN 872 standard (ASTM C 33-08), complying with what is specified therein [10].

Colorimetry in the fine aggregate.

This test was carried out to determine the color, based on the organic impurities contained in the fine aggregate, giving it a classification from 1 to 5 as per NTE INEN 855 (ASTM C 94, ICONTEC 3318) [11].

Unit weight of the aggregates.

This test was performed under the parameters of the NTE INEN 858 standard (ASTM C 29-09) indicated in Table 2, to determine the unit weights of the fine aggregate and coarse material [12].

Table 2. Characterization of the Aggregates.

Property	Fine aggregate	Coarse aggregate
Fineness modulus	3.01	*
Nominal maximum size (mm)	4.76	19.05
Abrasion Percentage (%)	*	32.6
Compacted Unit W. (kg/m³)	1640	1440
Specific Solid W. (kg/m³)	2660	2650
Moisture Content (%)	7.24	1.44
Absorption percentage (%)	6.30	2.67

Relative density and absorption of the fine aggregate.

This test is based on the NTE INEN 856, 857 standard (ASTM C 128-07a, ASTM C127-07), where it describes the determination of the relative density and the absorption of the fine aggregate [13].

Tire rubber recycling process

Steps for the Durallanta recycling process:

Initial inspection

In this first step, the technician performs a rigorous inspection, determining a severe damage to the tire that influences its approval or rejection.

Scraping

In this step, the remaining layer of the tire is removed (see Figure 1). Using precision equipment, the rim is prepared to receive the appropriate tread according to the specifications given by Durallanta (Scraping Radius).

Figure 1. Blade machine for the scraping process.

Collection of the scraping process

In this step, all the particles coming from the scraping of the tires are collected through ducts driven by an air pump into the collection area (see Figure 2), where the raw material used to make the prototype blocks is located.

Figure 2. Rubber extractor.

Concrete design

The mix for the conventional concrete was performed in accordance with A.C.I.211. This standard uses the properties of the aggregates and the required compressive strength [14].

Manufacturing of the prototype concrete blocks using rubber particles

For the production of the concrete prototype blocks, 390 mm x 190 mm x 140 mm molds required by the NTE INEN 3066 standard (ASTM C 90) were used.

The sampling of the concrete prototype blocks was carried out under the NTE INEN 2859-1 standard (ISO 2859-1); the NTE INEN 1778 Abrams cone was used to determine the settling of the mix, the value of which is used to measure the workability of the mix [15].

The factory curing procedure is to keep the blocks for the first seven days in humid conditions, wetting them in the morning and afternoon, covering them from the sun with a damp cotton blanket.

One way to cure the blocks is to spray them with water, using hoses (preferably with a spray) so that they do not dry out at any time. Another way to cure them is to cover them with canvases or cotton blankets that are permanently wet, or with plastic sheets that form an airtight environment that prevents moisture loss through evaporation. Covering them with black plastic and exposing them to the sun, accelerates the development of strength as long as the blocks are kept humid [16].

The rubber particles for the prototype blocks were obtained with the sieves shown in Table 1, where the mix material passing through sieve No. 10 and retained on sieves No. 12, No. 16 and No. 30 (see Figure 3) was collected. This was done to take the most advantage of the recycled material.

Figure 3. Particle size rubber retained in sieves No. 12, No. 16, and No. 30 (see Table 1).

With these recycled rubber particles, after performing the granulometric analysis (see Figure 4), the prototypes were manufactured, replacing the volume of the fine aggregate with rubber particles retained by the previously described sieves.

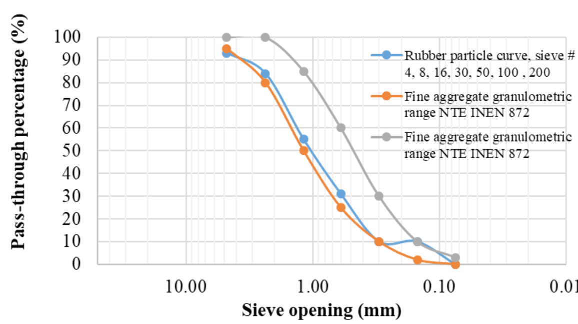

Figure 4. Recycled rubber granulometric curve.

Compression test carried out at 28 days, for this purpose three conventional non-structural type B blocks and 40 prototype blocks were tested.

Conventional non-structural type B concrete blocks and prototype concrete blocks for simple compression testing were used as entire units, where their net area can be determined by the procedure described in section D.5.5 of the NTE INEN 3066 standard for the simple compression test. The net area of the entire specimen must be considered, recording the maximum load reached by each specimen, to calculate the average stress of the conventional mix and the mixes containing rubber. This procedure is regulated in Annex E of the NTE INEN 3066 standard. The leveling of the specimens was performed according to the NTE INEN 2619 standard (ASTM C 1552-09a) [15].

Results and Discussion

Characterization results

The aggregate material from the Pifo sector, selected for this research are not within the NTE INEN 872 range. [10], for this the FULLER THOPSON method [14] had to be used to adjust the granulometric curve and estimate the content of sand and gravel, which resulted in 51% gravel and 49% sand. This is an aggregate with a high percentage of coarse particles, and this affects the water demand and the workability of the concrete. However, the variation referring to the standard is not significant to rule out the use of this material.

In the analysis of organic impurities with the NTE INEN 855 standard, a light yellowish color was visualized in the fine aggregate. This can be used in high strength concrete [11].

The dosage or proportion of the material had a ratio of 1:7:7 (cement - coarse aggregate - fine aggregate) by volume. The replacement percentages of the recycled rubber particles varies as follows: 10%, 15% and 20% by volume with fine aggregates.

For the volumetric design calculation of the mix, the volume of a 50 kg bag of cement was taken as a reference by using a steel container designed at 0.045 m^3 for the desired effect, in which it was necessary to internally graduate it to be able to calculate the percentages of recycled rubber particles to carry out the preparation of the mix, prior to the manufacturing of the concrete blocks.

Table 3 shows the quantities of the materials needed for the concrete mix. For this dosage, 5.6 containers of fine aggregate volume are needed for each cement bag. Since 20% was replaced, we obtained a value of 1.4 containers of rubber particles for the production of the prototype blocks.

Table 3. Dosage in volume used for the production of the prototype block using 20% of rubber particles substituting fine aggregates.

Material	m^3	L	Container	Cement
Cement				1 bag
Sand	0.252		5.6	
Gravel	0.315		7	
Water	0.048	48.00		
20% rubber container	0.063		1.4	
Note: 0.045m 3 container				

Mixing was done mechanically through a 0.70 m3 capacity industrial mixer acquired by the factory where the prototype blocks were made.

Once the materials are mixed, they are placed in the vibrating or blocking machine. The duration of the vibration, as well as the power of the engine of the vibrating machine are factors that significantly influence the strength of the blocks (approx. 20 seconds of vibration per mold).

When the concrete mix is placed in the blocking machine, it is compacted and consolidated based on the controlled pressure and vibration (see Figure 5). The filling method must be carried out in layers and with the help of a shovel the mix can be accommodated.

Figure 5. Vibrating or blocking machine.

Compression test results

The analysis of compression strength on

conventional concrete blocks and prototypes with 10%, 15% and 20% rubber particles replacement, were carried out 28 days after they were madee.

Table 4 shows the simple compressive strength test results, as well as the average compressive strength of the four samples made.

Table 4. Block Compressive Strength.

Sample	Age (days)	Conventional block type b (MPa)	Prototype block 10% (MPa)	Prototype block 15% (MPa)	Prototype block 20% (MPa)
1	28	6.24	5.24	4.89	3.92
2	28	5.52	5.19	5.22	3.41
3	28	5.77	5.08	5.09	3.79
Average	28	5.84	5.17	5.06	3.71

The conventional block without the addition of rubber powder designed and manufactured at the factory reached an average strength of 5.84 MPa. It was observed that the average strength of the prototype blocks with rubber particles at 10%, 15% and 20% are 5.17, 5.06 and 3.71 MPa respectively (see Figure 6). Then, we chose the prototype block that had 20% of rubber particles (greater use of particles) and that complies with the established strength for a non-structural type B block for the masonry that is being considered in this research.

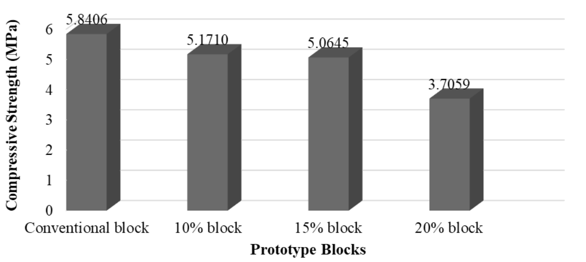

Figure 6. Average compressive strength, calculated from simple compressive strength test results.

The substitution of the fine aggregate with the rubber particles that have a lower density and resistance to fine aggregate causes the mechanical characteristics of the concrete to decrease (see Figure 7). Therefore, the strength of a composite material, such as concrete, depends on the strength of its components [17].

Figure 7. Prototype block compression test.

The decrease in compressive strength at 28 days of age of the different types of blocks tested with the percentages at 10%, 15% and 20% of rubber particles were 11.46%, 13.29% and 36.55 %, respectively (see Figure 8), related to the 100% of the strength reached by the conventional block.

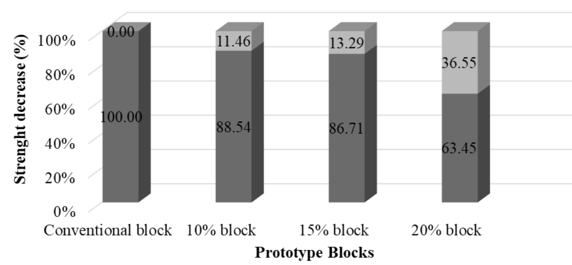

Figure 8. Decrease of compressive strength in prototype blocks compared to the conventional non-structural type B block.

Prototype Selection

Once the optimum percentage that meets the simple compressive strength test requirements was identified, a population of 70 specimens was obtained, for which a sample with more than 50% was taken, following L.P.J. Puerto [18], who states that when there is no research carried out previously on the type of subject being studied this should be placed at 50% of desired ratio and 50% of the unwanted ratio. Thus, 40 prototype blocks were verified in their dimensions, visual aspects and compressive strength, in order to determine the probabilistic data of the prototype.

This type of population is considered to be finite. In a finite population, according to R. Tulio [19], the elements in their totality are identifiable by the researcher, from the point of view of the knowledge possessed on the total quantity, that is to say when the researcher has a registry of all the elements that make up the research study.

When analyzing these data, we obtain the following results for the mean strength: a value of 3.7 MPa and a standard deviation of 0.35, this is a measure of the degree of dispersion of the analyzed data with respect to the average value. Thus we interpret that the degree of dispersion to be less than 1; as indicated in Figure 9, then these data is reliable for the proposed research according to R. Tulio [19].

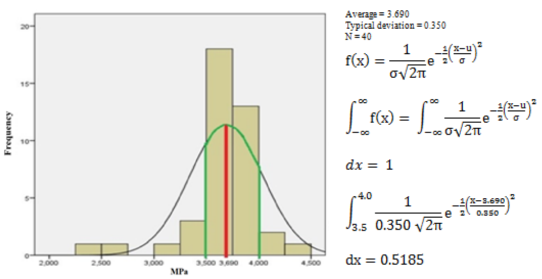

Figure 9. Gaussian bell normal distribution.

When determining the Gaussian bell, the result of the 40 specimens is: 51.85% of the total of the samples tested are within the sought MPa strength (3.5 - 4.0).

Manufacturing costs of the analyzed blocks

The costs obtained for manufacturing a conventional non-structural type B block and a prototype concrete block substituting 20% with rubber particles, with the established dosage 1:7:7 and 1:7:5.6 respectively, are summarized below:

Figure 10 shows the cost of making the conventional type B block at a value of $ 0.39 and the cost of the prototype block is $ 0.38.

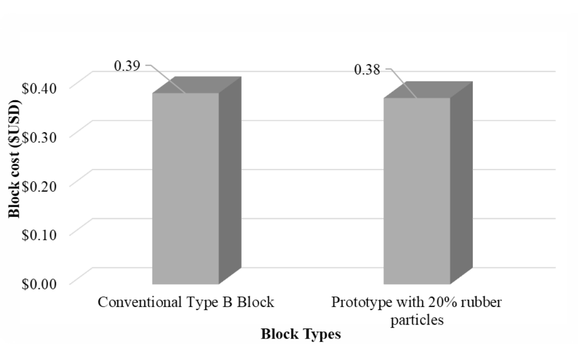

Figure 10. Manufacturing cost of conventional block compared to prototype.

As we can see the cost of the conventional type B block is upper than the prototype, this is due to the fact that the fine material was replaced by rubber particles, thus obtaining the saving of one cent of a dollar. For the purpose of this research, a batch of 70 specimens was obtained, resulting in the savings indicated above. Therefore it is evident that when considering a daily production with an estimated of 80 bags of cement, producing 5,600 blocks, that is, an annual block production of 2,044,000 specimens, resulting in an annual production savings of $20,440. The annual economic savings are very significant, since they encourage increasing production to achieve greater profit in the Ecuadorian Company, in addition to indirectly contributing to environmental decontamination by lowering the rate of environmental impact caused by rubber in its decomposition process.

Conclusions

The use of the recycled rubber particles retained in sieves No. 12, No. 16 and No. 30 was performed in order to optimize and to take advantage of the maximum recycled material from the Durallanta factory and to contribute in the reduction of the environmental impact currently registered in the city.

The type B conventional concrete block subjected to the simple compression test had a performance of 5.84 MPa, for which it was designed. The prototype block with 10%, 15% and 20% rubber particle substitution had 5.17, 5.06 and 3.71 MPa respectively. Therefore, the prototype concrete block using a 20% rubber particle substitution was chosen because it meets the minimum net compressive strength of the NTE INEN 3066 standard required in this research.

The decrease in compressive strength at 28 days of age of the prototype concrete block tested with 20% rubber particles was 36.55% (3.71MPa), compared to 100% (5.84MPa) of the strength reached by the conventional type B concrete block, despite the fact that this reduction occurred, the prototype block is within the required strength.

A standard deviation of 0.35 and variation coefficients of less than 1 were obtained for all variables, which means that the results were homogeneous and with a low degree of dispersion. Therefore, we can determine that the optimum percentage of rubber particles is 20% with respect to the volume of fine aggregate used in the mix, and the desired compressive strength for the research was achieved.

Within the unit price analysis for the production of conventional and prototype concrete blocks, the prototype block is cheaper. This is because a percentage of fine aggregate was replaced by rubber particles obtaining an inferior value on that item. The rest of the materials, labor and equipment are similar.

The unit price of the conventional type B concrete block for the proposed dosage has a higher market value, while the prototype has a lower value. Thus, the feasibility, the cost-benefit relationship is adequate given what we presented above. The analysis of unit prices finally concluded that there are economic savings with the concrete prototype with 20% rubber particles compared to the conventional type B block.

Finally, this research has shown that the prototype block complies with the NTE INEN 3066 standard. It also helps to mitigate the environmental impact produced by the contamination of discarded tires.

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