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Possibilidade de utilizar resíduos de pneus inservíveis na composição de misturas para fabricação de blocos de cimento

Possibility to use waste tire waste in the composition of mixtures for the manufacture of cement blocks

Posibilidad de utilizar residuos de llantas de desecho en la fabricación de bloques de cemento

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Resumo

O estilo de vida moderno levou a um aumento na quantidade de resíduos sólidos no mundo, e os de pneus inservíveis são um dos mais gerados. Anualmente bilhões de toneladas de resíduos de pneus são produzidos, então nesse estudo, procurou-se reutilizá-los para confeccionar materiais para a construção civil. Para isso, foi realizada uma pesquisa em laboratório onde foram confeccionadas amostras em cilindros de 50 x 100 mm com traços de 0, 10, 15 e 20% (em peso) de resíduo, além do cimento, areia natural e água. Foi realizada a distribuição granulométrica dos resíduos de pneus e também da areia. E, com as amostras em cilindros, avaliaram-se as propriedades físicas e mecânicas como absorção de água e massa específica aparente, além da análise da resistência mecânica a compressão e o módulo de elasticidade. Os resultados mostraram que a distribuição granulométrica do resíduo de pneu se encaixa como um agregado fino, similar a granulometria da areia. A taxa de absorção de água dos corpos de prova com resíduos foi inferior a 10%. No entanto, a resistência mecânica diminui proporcionalmente conforme a quantidade de resíduos de pneus aumentou. Porém, ao analisar o comportamento das curvas tensão x deformação, os corpos de prova contendo resíduos, se tornaram mais flexíveis, pois são capazes de suportar cargas além da tensão máxima. Dessa maneira, a resistência e a capacidade de absorver energia foram aumentadas. Concluímos que é possível incorporar certas quantidades de resíduos de pneus em blocos para a construção civil, mas sem função estrutural.

Palavras-chave: Preservação ambiental; Resíduos de pneus; Propriedades mecânicas; Comportamento deformação por tensão.

Abstract

The modern lifestyle has led to an increase in the amount of solid waste in the world, and waste tires are one of the most generated. Annually billions of tons of waste tires are produced, so in this study, we sought to reuse them to make materials for civil construction. For this, a laboratory research was carried out where samples were made in 50 x 100 mm cylinders with traces of 0, 10, 15 and 20% (by weight) of waste, in addition to cement, natural sand and water. The granulometric distribution of waste tires and sand was also carried out. And, with the samples in cylinders, the physical and mechanical properties were evaluated, such as water absorption and apparent density, in addition to the analysis of the mechanical resistance to compression and the modulus of elasticity. The results showed that the granulometric distribution of the tire residue fits as a fine aggregate, similar to the sand granulometry. The water absorption rate of the waste specimens was less than 10%. However, the mechanical resistance decreases proportionally as the amount of tire waste has increased. However, when analyzing the behavior of the stress x strain curves, the specimens containing residues, became more flexible, as they are capable of supporting loads beyond the maximum stress. In this way, the resistance and the ability to absorb energy were increased. We concluded that it is possible to incorporate certain quantities of waste tires in blocks for civil construction, but without a structural function.

Keywords: Environmental preservation; Tire waste; mechanical properties; Tension-deformation behavior.

Resumen

El estilo de vida moderno ha llevado a un aumento en la cantidad de desechos sólidos en el mundo, y las llantas de desecho son una de las más generadas. Anualmente se producen miles de millones de toneladas de llantas de desecho, por lo que en este estudio, buscamos reutilizarlas para fabricar materiales para la construcción civil. Para ello, se realizó una investigación de laboratorio en la que se realizaron muestras en cilindros de 50 x 100 mm con trazas de residuos de 0, 10, 15 y 20% (en peso), además de cemento, arena natural y agua. También se realizó la distribución granulométrica de llantas de desecho y arena. Y, con las muestras en cilindros, se evaluaron las propiedades físicas y mecánicas, como la absorción de agua y la densidad aparente, además del análisis de la resistencia mecánica a la compresión y el módulo de elasticidad. Los resultados mostraron que la distribución granulométrica del residuo del neumático se ajusta como un agregado fino, similar a la granulometría de arena. La tasa de absorción de agua de las muestras de residuos fue inferior al 10%. Sin embargo, la resistencia mecánica disminuye proporcionalmente a medida que aumenta la cantidad de desperdicio de neumáticos. Sin embargo, al analizar el comportamiento de las curvas de tensión x deformación, las muestras que contienen residuos se volvieron más flexibles, ya que son capaces de soportar cargas más allá de la tensión máxima. De esta manera, aumentaron la resistencia y la capacidad de absorber energía. Llegamos a la conclusión de que es posible incorporar ciertas cantidades de llantas de desecho en bloques para la construcción civil, pero sin una función estructural.

Palabras clave: Preservación ambiental; Desperdicio de llantas; Propiedades mecânicas; Comportamiento de tensión-deformación.

1. Introduction

One of the solid wastes that most concerns environmentalists, society and the government is tire waste. Tires take about 600 years to decompose (Andrade, 2007). Disposing of unserviceable tires is a global problem, it is estimated that almost 1,0000 million tires end their service life each year and over 50 % are discarded (Barbuta, Rujanu, & Nicuta, 2016). The practice of improper disposal includes the burning process, which has proven to create serious fire and environmental pollution hazards. And landfill disposal has become difficult due to depletion of available sites, the risk of fire, environmental pollution and enhanced the accumulation of water in tires is attractive for breeding mosquitoes and disease-bearing rodents (Thomas, Gupta, & Panicker, 2016)

By the year 2030, the number of waste tires can reach 1,200 million tires per year. If we include the stocked tires, there would be 5,000 million tires to be discarded regularly (Thomas et al., 2016). In Brazil, according to data from RECICLANIP, the managing entity of the reverse logistics system of waste tires, from 1999 to 2018, 4.5 tons of unserviceable tires were collected, equivalent to 898 million tires. This entity began to collect unserviceable tires after the approval of Law number 9.605 of 1998 - IBAMA (Brazilian Ministry of Environment). This law states that, in view of the fact that unused or improperly disposed tires are a serious environmental liability, it has imposed on manufacturers and importers of such utensils the obligation to collect and dispose of them environmentally appropriate in their national territory (Ibama), 1999). Therefore, there are a lot of unserviceable tires that can be reused, because the waste reuse is an interesting alternative and presents clear advantages from economic (cost reduction) and ecological (resource saving) perspectives ((Ibama), 1999; Thomas et al., 2016; Zak et al., 2015).

To encourage sustainable development has put pressure on all industrial areas, including construction, to implement appropriate methods to protect the environment. Due to current global concerns that have arisen from extensive environmental problems such as climate change and resource impoverishment, coupled with rapid technological advances in the construction sector, interest in alternative building materials has developed because the concept of sustainability is gaining importance worldwide. An alternative found is to reuse unserviceable materials as a raw material for building materials. That in this case, waste from unserviceable tires was used instead of natural raw material.

Tires have a complex composition, basically a common tire is made up of 27 % synthetic rubber, 14 % natural rubber, 28 % carbon black, 17 % petroleum and chemical derivatives, 10 % steel and 4 % textile, which are also chemicals, a mixture that would take around 600 years to decompose. For these reasons, a Resolution was created in 1999 by the National Environmental Council, which prohibits the improper final disposal of unserviceable tires, i.e. discarding at sea, rivers, lakes, wastelands, landfills and prohibits their burning. in the open, as its burning produces toxic smoke that is harmful to health and the environment (Norbert Suchanek, 2017).

Because of these all problems, universities should invest in research to at least try to reduce environmental degradation and improve the quality of life of the population. Thus, in this study alternatives are sought to reuse waste that causes serious problems to the environment, inserting it in materials for civil construction.

1.1. Application of unserviceable tires

In the last years, many researchers around the world are trying to find alternatives to reusing unserviceable tires. Alternatives include use as fuel in cement kilns and use in asphalt pavements. Using tires as a fuel is technically feasible but not economically attractive. Also, this practice pollutes the environment by emitting large amounts of carbon dioxide. Asphalt pavement use is technically and economically viable, but only a small percentage of waste is used [3]. One of the possible solutions for the use of tire waste would be to incorporate in cement-based materials to replace some of the natural aggregates. Concrete is one of the most commonly used materials in construction due to the availability of its materials, its versatility, durability and performance. Higher to providing adequate structure life at a cost competitive with other materials, it enables the large-scale use of potentially environmentally polluting wastes from other industrial processes (Tutikian, Isaia, & Helene, 2011). Several authors have studied and confirmed the feasibility of using fragmented rubber in addition or substitution of natural aggregate in concrete (Ferreira, Gachet-Barbosa, Cecche Lintz, Russo Seydell, & Jaquiê Ribeiro, 2013; Issa & Salem, 2013; Ling, 2012; Lintz, Barbosa, Seydell, & Jacintho, 2010; Pelisser, Zavarise, Longo, & Bernardin, 2011; Shen et al., 2013; Verzegnassi, Lintz, Barbosa, & Jacintho, 2012). One of the properties of rubber concrete is greater ductility, i.e., rubber concrete provides greater deformation capacity before rupture. Sang Son et al.(Son, Hajirasouliha, & Pilakoutas, 2011) noted that the use of 1 % fragmented rubber (1 % of the total aggregate weight) in the concrete mix can result in a 90 % improvement in the curvature ductility of reinforced concrete columns, with the possibility of being used in seismic applications. The main limitation of using fragmented rubber as an aggregate in concrete is the reduction in compressive strength. However, some researchers have found that, at appropriate levels, rubber has improved this feature of concrete. Yung et al.(Yung et al., 2013) found that with the replacement of fine aggregate by 5 % volume rubber tire waste, the compressive strength was increased by 10 %. The increase in compressive strength when the replacement of natural aggregate by rubber is made in concrete is related to the existence of an optimum ratio of replacement volume of rubber aggregate to mineral (T. D. Silva, Paula, & Silva, 2017).

(Gesolu & Güneyisi, 2011) explained that the use of fragmented rubber waste as aggregates prolonged setting time and the viscosity of concrete. (Issa & Salem, 2013) studied the use of these wastes as fine aggregates in concrete. They recorded good compressive strength for less than 25 % substitutions (for fine aggregates), while the big drop was noted beyond 25 % substitutions. In specimens with 25% fragmented rubber, a reduction in concrete density of almost 8% was noted. (Dong, Huang, & Shu, 2013) explained that compressive and split tensile strength of treated rubber concrete increased by 10 to 20 % when compared to concrete with uncoated rubber. The chloride ion resistance of coated rubber concrete and non-rubber concrete was almost similar. The energy absorbing capacity of rubber-coated concrete showed improvement. (Yilmaz & Degirmenci, 2009) observed a decrease in water absorption upon an increase in the size of rubber particles in concrete. (Bravo & De Brito, 2012) reported that water absorption through the dipping process increases as rubber percentage and rubber particle size increase. (Sadek, El-Attar, & Ali, 2016) also developed a study to evaluate the effect of tire rubber on the properties, this time, of soil-cement bricks and, consequently, on the structural behavior of compressed masonry walls. The rubber used by the authors was free of steel and textile fibers and was used in two sizes to replace the large and fine aggregates. It was also noted that the amount of water absorbed by concrete increased with the increase in the amount of rubber granules (T. D. Silva et al., 2017). These findings reveal that the properties of tire-waste concrete are influenced by particle size, quantity and processing. Researches have been investigated the incorporation of tire waste just on concrete (Table 1).

Table 1 - Summary of research on tire waste and key findings.

References	Replacement Quantity	Key Findings
(Khaloo, Dehestani, & Rahmatabadi, 2008)	12.5, 25, 37.5 and 50%	It was observed that the concrete fracture with the addition of tire residue occurred more smoothly and homogeneously. There was no separation in pieces of the samples either. However, the mechanical resistance to compression decreases as the amount of waste tire incorporation has increased.
(Gesolu & Güneyisi, 2011)	0, 5, 15 and 25%	A decrease in compressive strength and an increase in concrete viscosity were observed with the addition of tire residue.
(Son et al., 2011)	1 %	Rubberized concrete provides greater deformation capacity before breaking. They observed improved ductility of the curvature of reinforced concrete columns, with the possibility of being used in seismic applications.
(Yung et al., 2013)	5, 10, 15 and 20%	By replacing the fine aggregate with 5% volume rubber tire waste, the compressive strength was increased by 10%.
(Issa & Salem, 2013)	15, 25, 50 and 100%	Good compressive strength results with rubber contents of less than 25% in place of crushed sand. Lower density - lower weight. Improved concrete ductility, which can be used on road barriers or other similar shock-resistant elements. Improved damping properties as rubber absorbs vibration largely.
(Dong et al., 2013)	15 and 30%	It was found that there was increased ductility and toughness of samples containing tire residue.
(F. M. Da Silva, Gachet Barbosa, Lintz, & Jacintho, 2015)	10 to 50%	The increase in compressive strength when the replacement of natural aggregate by rubber is made in concrete is related to the existence of an optimum ratio of replacement volume of rubber aggregate to mineral.
(Thomas et	0% to 20% in	Built-in tire-waste concrete is highly resistant to harsh

al., 2016)	multiples of 2.5%	chloride-containing environments and can be implemented in areas where there is a possibility of acid attack.
(Li, Zhuge, Gravina, & Mills, 2018)	6, 12 and 18%	The results showed that the concrete with tire residue showed higher compression toughness and consequently improved energy absorption under compression load.
(Zhu, Dai, Chen, & Liang, 2019)	5, 10 and 15%	Experimental results show that the smaller the particle size the more resistant the concrete is, that there is a relationship between particle size and strength.
(Jalal, Nassir, & Jalal, 2019)	10 and 15%	The results indicated that the incorporation of tire residue between 10% and 15% led to a 30% and 50% decrease in mechanical resistance respectively. Consequently, there was a reduction in the modulus of elasticity.

Source: The authors.

Observing the Table 1, it is concluded that the use of waste tires can be used in various cementitious materials with promising results according to its application. In this way, the authors decided to analyze the use of the residue to compose the mixture of cement blocks and to verify the mechanical resistance to compression, water absorption, aging and elasticity module. The standard also establishes the nominal dimensions of width, height and wall thickness of the rectangular hollow blocks. However, Frasson Jr (2000) found that there is a relationship between the mechanical strength of hollow cement blocks and cylindrical specimens 5x10 of the same line and of the same specific mass. The strength ratio of the 5 x 10 specimens corresponds to 80% of the strength of the hollow blocks (Frasson Junior, 2000). The standard NBR 6136 (ABNT, 2016) specifies that the hollow blocks must meet the established limits of resistance, absorption and shrinkage by drying according to Table 2.

Table 2 - Requirements for mechanical strength, water absorption and shrinkage.

Classification	Types	Characteristic compressive strength (MPa)	Water absorption (%) Natural aggregate		Shrinkage (%)
			Individual	Average	
Structural function	A	≥ 8.0	≤ 9	≤ 8	≤ 0.065
	B	4.0 ≥ 8.0	≤ 10.0	≤ 9.0	
No structural function	C	≥ 3.0	≤ 11	≤ 10	

Source: ABNT 6136: (2016).

In Table 2, it is also possible to observe that the NBR 6136 standard classifies the blocks in three different types, A, B and C. Since only C has no structural function.

Although there are some studies focusing on the use of tire waste in concrete technology, the performance of tire waste has not been evaluated when used to replace natural aggregates in cement blocks. In addition to the insertion of waste, it was also sought to eliminate the burning process, thus avoiding the waste of electricity and the use of firewood and also to avoid air pollution by smoke. In order to analyze the influence of tire residue on the mechanical properties of concrete blocks the tests were carried out on cylindrical specimens of 5 x 10 cm due to the fact that they are easier to handle and consume smaller amounts of material

Therefore, the objective of this study was to determine the feasibility of using these fragmented residues in mixtures for the production of hollow cement blocks without a structural function for civil construction. The properties of resistance to axial compression, absorption, durability and dynamic elasticity module were evaluated.

2. Materials and Methods

Based on the techniques suggested by Pereira et al. (2018) this research was organized as follows: (1) survey of the problem; (2) formulation of strategies for reuse; (3) literature review on the topic; (4) development of the research that consisted in the making of the specimens and analysis of results (Pereira et al.,2018).

Therefore, for this study it was necessary to make cylindrical specimens with different compositions: 0, 10, 15 and 20% by mass of tire residue. Following norms of the Brazilian Association of Technical Standards (ABNT) for specimens used to evaluate physical and

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mechanical properties of materials that contain cement in their composition. In addition, tests were carried out to evaluate the granulometry of the crushed waste from waste tires and the natural aggregate, in this case sand. Therefore, it is a laboratory research of a quantitative nature that aims to use unserviceable residues to manufacture materials for civil construction. Thus, the intention of this study is to contribute to the preservation of our planet by making it more sustainable.

2.1 Sample preparation

First, to manufacture the samples (cement blocks), was necessary to study the amount of waste which could replace the natural aggregate. For the composition of concrete block compositions with waste incorporation, the following materials were used: sand, cement (type CPV ARI – Campeão Brand), water and waste granulate of unserviceable tires. Table 3 shows the physical and chemical characteristics, informed by the manufacturer, of the type of cement used in this study.

Table 3 - Physical and chemical characteristics of cement CPV ARI – Campeão Brand).

Parameters	
Especific mass gravity	3,04 g/cm^3
Apparent specific mass	-
Fineness Module	1%
Specific area	5200 cm^2/g
pH in aqueous solution	12 to 14
Color	Gray
D_{10}	7,92 µm
D_{50}	11,76 µm
D_{90}	30,33 µm

Source: CRH Brasil.

Table 3 shows that the cement complies with the specification of the ABNT NBR 16697/2018 standard.

Granulated waste rubber from untreated tires (Figure 1), which is basically composed of rubber which is the predominant material, being 27 % synthetic and 14 % natural, carbon black constitutes 28 % of the composition. Petroleum and chemical products account for 17 %, metallic material (or steel) for 10 % and textile for 4%.

Figure 1 - Untreatd waste tires and natural sand.

Source: The authors.

The tire residue has a granulometry similar to natural sand, as can be seen in Figure 1. The natural sand extracted from the river was acquired in local commerce and water treated by the concessionaire COPASA MG. The particle size distribution was evaluated in an oven-dried sample at 105°C for 24h and verified using the normal 4.75 mm mesh series; 2.36 mm; 1.18 mm; 0.6 mm; 0.3 mm; 0.15 mm and 0.075 mm mesh intermediate sieve (NBR 7211, ABNT, 2005). The Fineness Module was determined by the sum of the aggregate retained mass accumulated percentages in the normal series sieves divided by 100.

To produce concrete samples with tire waste incorporation, four traits were hereinafter referred to as Ref, T10, T15 and T20, that is, with 0, 10, 15 and 20% (wt. %) of sand replacement. Table 4 presents the traits used.

Table 4 - Traces used for the manufacture of cylindricals samples.

Trace	Cement	Sand	Tire	Water
Reference	1	7	0	1
T10	1	6,3	0,7	1
T15	1	5,95	1,05	1
T20	1	5,6	1,4	1

Source: The authors.

Table 4 specifies, in the unitary line, that for a part of cement, how many parts must compose the studied mixtures.

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Once properly weighed, the materials were mixed using an electric mixer. Eighteen specimens were made for each mixture, using metal cylinders of diameter 50 mm and height 100 mm, as shown in the Figure 2.

Figure 2 - Cylindrical specimens.

Source: The authors.

The demolding of the specimens was performed after 24 h and was kept in a humid chamber with 90% humidity on average until the date of the tests.

2.2 Sample characterization

The tests were performed to evaluate the quality of the concrete samples, adding the tire residue and analyzing if they meet the technical standards of the Brazilian Association of Technical Standards (ABNT). The compressive strength, absorption and durability tests were performed as described in Table 5.

Table 5 - Tests and respective technical standards, specimens and ages.

Trials	Rule of ABNT (Brazilian Association of Technical Standards)	Proof bodies	Trials dates (days)
Compressive strength	NBR 6136/2016	12 cylinders Ø 5 x 120 cm	7 and 28
Immersion absorption	NBR (Brazilian rule) 13555/2012	3 cylinders Ø 5 x 10 cm	30
Durability	NBR (Brazilian rule)13554/1996	3 cylinders Ø 5 x 10 cm	7
Dynamic modulus of elasticity	ASTM 1876-01	3 cylinders Ø 5 x 10 cm	30

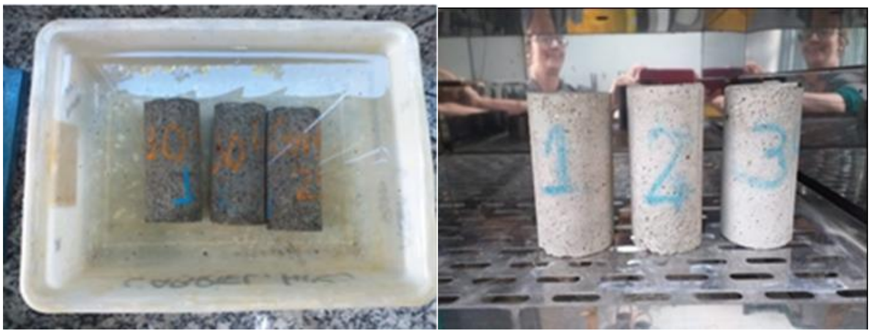
Source: The authors.

The number of specimens and curing time for carrying out the tests was determined according to the current regulations, as shown in Table 5.

The compressive strength was evaluated per ABNT NBR 6136/2016 at 7 and 28 days, using INSTRON equipment, mod. 8801 with a load application of 50 kgf/s. The water absorption test was performed according to NBR 13555 (ABNT, 2012) 30 days after molding. It consisted of placing the 3 specimens in an oven at 105 °C until mass constancy obtaining the dry mass, m1, in grams (g). At room temperature, the sample was immersed in water for 24 h as shown in Figure 4 (a) and (b). Saturated mass (m 2) was measured after drying the specimens lightly with a damp cloth.

To analyze wetting and drying durability, specimens were kept in a humid chamber for 7 days after molding. Identified as 1, 2 and 3 which sample 1 was used for volume variation and samples 2 and 3 for mass loss. The samples was immersed in water for 5 h and weighed after light drying with a damp cloth, Figure 3 (a) and (b). After the wetting step the samples were taken to the oven for 42 h at 105°C. Then weighed and the volume of sample 1 calculated. This 48 hours cycle was repeated six times. After the six cycles of wetting and drying the specimens were brought to the oven at 105 °C until mass constancy. This way it was possible to dimension the volume and mass variation.

Figure 3 - (a) Water immersed specimens and (b) oven dried specimens.



(a) (b)

Source: The authors.

The Figure 3 (a) shows the specimens immersed in water and (b) placed in an oven at 105ºC. Procedure used for wetting and drying absorption and aging tests.

For the application of the Impulse Excitation Technique, ASTM E1876 was used, the Sonelastic equipment in the following configuration: Sonelastic software version 3.0, adjustable support for SA-BC bars and cylinders, CA-DP directional acoustic pickup and manual pulsator. three specimens were produced for each block trace that were tested at 28 days of curing.

3. Results and Discussion

It is observed in Table 6 and Figure 4 that the particle size distribution of the tire dust fits the definition of NBR 7211 (ABNT, 2005) as a fine aggregate; that is, from 0.15 mm to 4.8 mm. It resembles the sand used in which the highest concentration of particles is between the 1.2 mm and 0.3 mm mesh sieves.

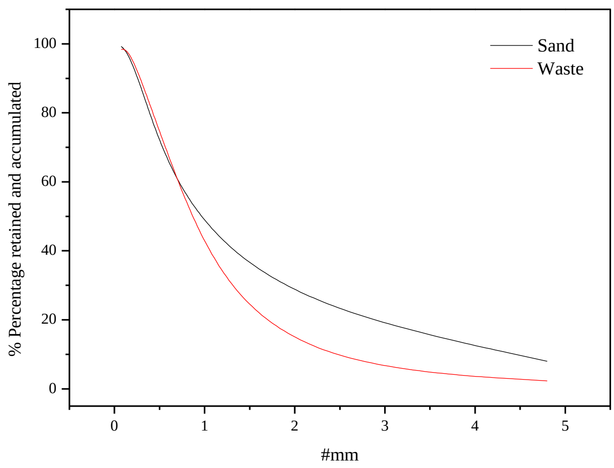
Table 6 - Sand and tire waste granulometry.

Sieve #	% retained and accumulated	
	Sand	Tire
4.8	8.01	2.33
2.4	21.61	6.14
1.2	40.10	27.45
0.6	63.05	66.84
0.3	87.30	89.59
0.15	97.48	98.41
0.075	99.26	98.41
Bottom	100.00	100.00
Thin Mass	3.18	2.91
Specific mass	2.48	0.781

Source: The authors.

In this case, as seen in Table 6, the granulometry resembles the sand used which the highest concentration of particles is found between the 1.2 mm and 0.3 mm sieves. The specific mass of the tire is approximately three times less than that of sand.

Figure 4 - Particle size curve of sand and tire residue.



Source: The authors.

The granulometric curves (Figure4) confirm the similarity between the tire residue and sand being suitable as fine aggregate for the composition of the mixture.

According to the Brazilian technical standard, NBR 6136: 2014, the water absorption rate for concrete blocks must be less than or equal to 10 %. Thus, in Table 7, it is observed that all mixtures with tire residue have values below the limit of the standard, meeting the established requirement. This physical property is one of the most important as it is related to the mechanical strength of the material.

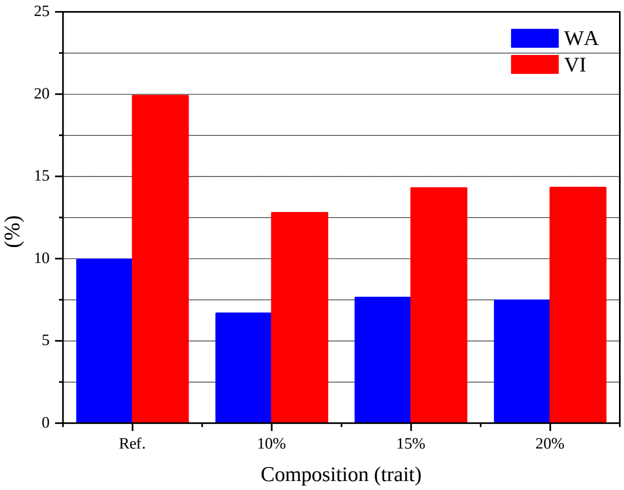
Table 7 - Results of immersion absorption tests.

Trace	Specific mass (kg/m^3)			Water Absorption	Voids Index
	ρDry	ρSatured	ρReal	WA (%)	VI (%)
Reference	2.0	2.2	2.5	9.9	19.9
T10	1.9	2.0	2.2	6.7	12.8
T15	1.9	2.0	2.9	7.6	14.3
T20	1.9	2.0	2.2	7.5	14.3

Source: The authors.

As shown in Table 7, it can be seen that the absorption and void index of mixtures with tires were lower than the reference mixture without residue. By analyzing the graph, Figure 5, it can be observed that the T10 samples had the lowest water absorption rates. This behavior is probably due to rubber because it is an elastomer and has hydrophobic behavior.

Figure 5 - Compositions and respective water absorption (WA) and void index (VI) values.



Source: The authors.

The graph (Figure 5) shows the results in bar charts and thus it is clearly observed how much the water absorption (WA) values decrease in the compositions with residues, consequently the void index (VI) also decrease.

When checking the mechanical strength of the samples one must be aware that there are some criteria that influence the results. These criteria are the characteristics of the raw materials, the water / cement factor, aggregate particle size, the traces, mixing time, vibration, pressing, curing conditions, material execution and handling.

By analyzing the results of the compressive strength, it can be observed, Table 8, that the greater the addition of tire residue, the lower the resistance. The Figure 6 shows this behavior of the samples. The resistance only increases with the reference sample after the aging process, whereas with the tire residue samples, the difference in resistance after aging is not relevant.

Analyzing the results of mechanical resistance and modulus of elasticity in Table 8, it is observed that the greater the addition of waste tires, the lower the mechanical resistance.

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Table 8 - Compressive strength and modulus of elasticity results.

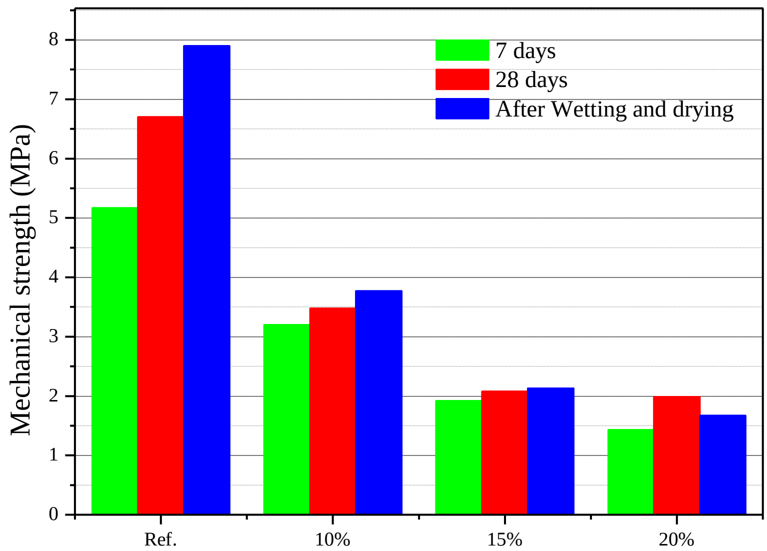
Samples	Compressive strength (MPa)		After wetting and drying	Modulus of elasticity (GPa)
	7 days	28 days		
Reference	5.38	6.70	0.90	15.5
10 %	3.20	3.48	3.77	4.19
15 %	1.92	2.08	2.13	3.66
20 %	1.43	1.9	1.67	1.44

Source: The authors.

It is also possible to note that there was a reduction in the modulus of elasticity, that is, at the same stress level, samples with tire residue suffered greater deformation than samples without residue. This can be favorable for certain applications when the material is subject to impact and dynamic loads.

In Figure 6, it can be seen that the resistance only increases with the reference sample after the aging process, while with the waste tire samples, the difference in resistance after aging is not relevant.

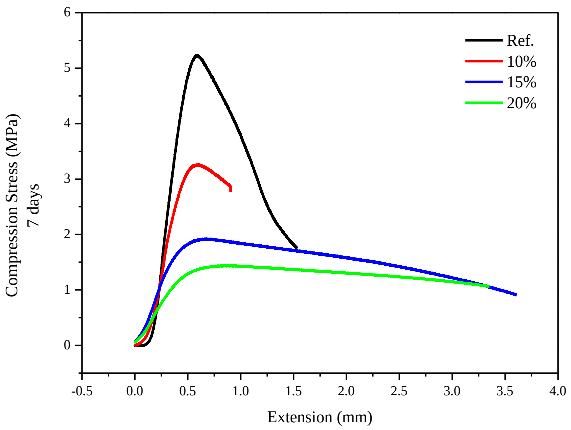
Figure 6 - Comparative bar chart: strength x time x trace after 7 days, 28 days and after aging process.



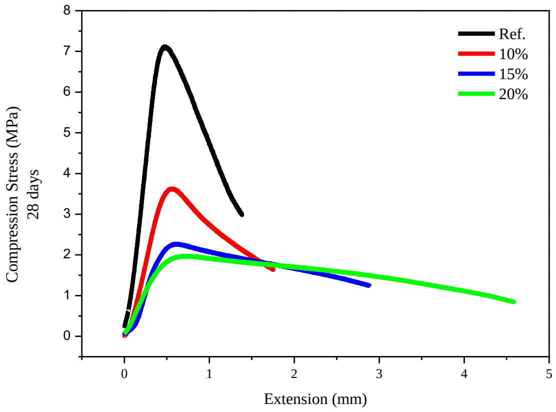
Source: The authors.

However, by observing the behavior of the stress x strain curves, Figure 7 (a) (b) and (c), it is noted that the samples containing tire residue have become more flexible, because it is noticed that these blocks are capable of supporting loads beyond the maximum stress, which authors as (Dong et al., 2013; Khaloo et al., 2008) call it fail-resistance or crack resistance.

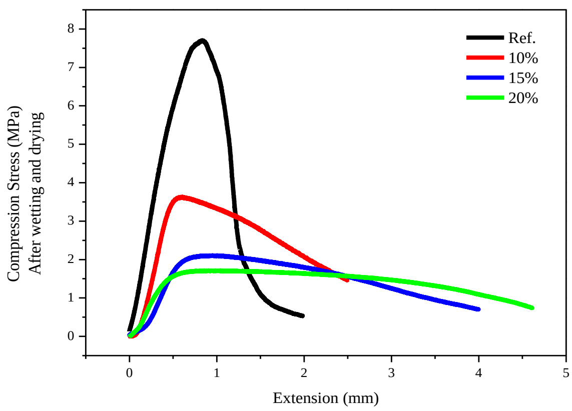
Figure 7 - Stress x Strain to compression curves, (a) after 7 days of cure, (b) after 28 days and (c) after aging.



(a)



(b)

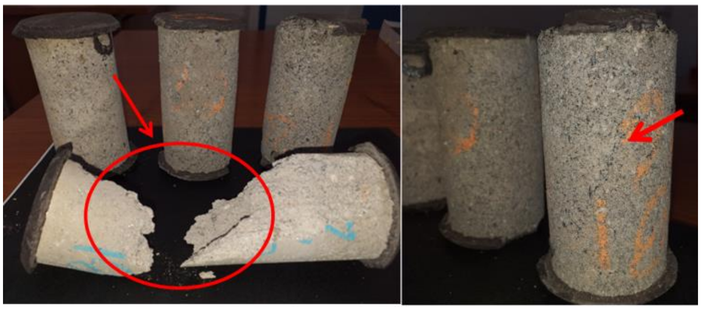


(c)

Source: The authors.

Thus, the tenacity and the ability to absorb energy were increased. The type of fracture became different with the addition of tire waste, the blocks without the addition of tire waste suffered abrupt and catastrophic fractures, as expected from this type of material. However, the blocks with the addition of waste were able to have a behavior similar to that of a polymeric material, this kind of behavior was also observed by Khaloo et al. (2008) and Son et al. (2011) (Khaloo et al., 2008; Son et al., 2011). The increase in nonlinearity of the samples with addition of tire residue may explain the more scattered failures, since the replacement of mineral aggregates by the tire residue seems to allow a more uniform crack development and smoother fracture propagation compared to samples without addition of tire residue. Waste-added blocks did not show fragile and / or catastrophic fractures under compression. Looking at the images in Figure 8 (a) and (b) it can be seen that the failure states in the tire-free samples show a division of the specimen.

Figure 8 - Specimens after compressive strength testing, (a) the front sample without addition of tire residue and the bottom, samples with addition of tire residue and (b) specimens with tire residue, the arrow points to one of the cracks formed during the compressive strength test.



Source: The authors.

As can been seen, Figure 8, for samples with tire residue the failure was not accompanied by any detachment, probably due to the homogeneous crack formation caused by the rubber particles.

It has been found that ceramic toughness can be improved by developing a new generation of ceramic matrix composites consisting of particulates, fibers or whiskers (Callister, Jr., 2012). Whiskers are monocrystalline fibers normally made of silicon carbide and nitride that, when added to a ceramic matrix, result in increased fracture resistance. Crack initiation usually occurs in the matrix phase, while crack propagation is prevented or delayed by particles, fibers or whiskers (Callister, Jr., 2012). Interestingly, the tire waste fibers behave similarly to whiskers: These fibers inhibit crack propagation and absorb energy, while tearing the tire fibers peel off the matrix causing stress redistribution in the regions adjacent to the crack ends. In general, increasing tire waste fiber content decreased strength but increased fracture toughness compared to its non-residue analogues. Due to a low modulus of elasticity relative to mineral aggregates, the rubber particles act as large pores and this generates a significant drop in resistance to applied loads. Thus, the greater the amount of tire waste incorporated into the composition, the lower the compressive strength. (Son et al., 2011) observed that the use of only 1 % fragmented rubber (1 % of the aggregate total weight) in the concrete mix can result in a 90% improvement in reinforced concrete ductility. Thus, the use of tire residue on concrete blocks can provide a very peculiar type of mechanical and fracture characteristic (Son et al., 2011). As these samples have greater energy dissipation capacity and greater ductility, they could be applied when the element is subjected to impact and dynamic loads. Table 9 presents the results of the modulus of elasticity.

Table 9 - Table with the averages of the results of the measurements of the elasticity modules in GPa.

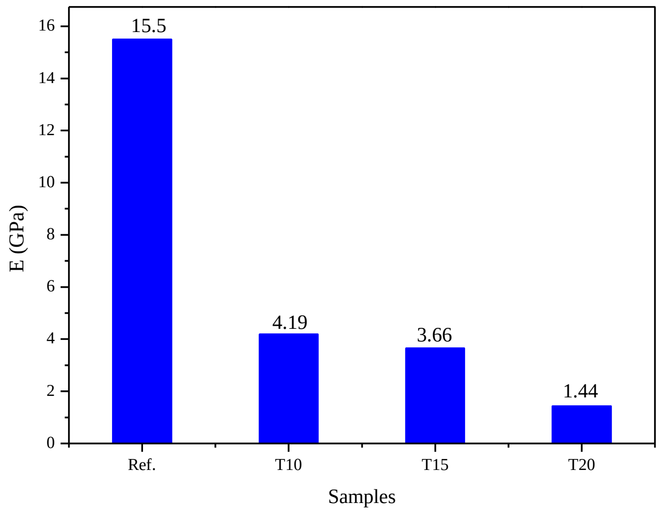
Samples	Modulus of elasticity (GPa)
Ref.	15.5
T10	4.19
T15	3.66
T20	1.44

Source: The authors.

By observing the results of the modulus of elasticity, also known as Young's Modulus, Table 9, it is possible to state that the modulus of elasticity of blocks with added tire residue is substantially lower than the block without residue (sample Ref.).

From the results shown in Figure 9, it is possible to observe that there was a reduction in the modulus of elasticity, so it can be at the same level of tension, with in the elastic regime of the material. So, the samples with tire waste will deform more than its analogues without rubber, which can be favorable for certain applications, such as when the element is subject to impact and dynamic loads.

Figure 9 - Average values of the Modulus of elasticity.



Source: The authors.

In the graph shown in Figure 9, it is possible to note the dramatic reduction in the modulus of elasticity, or Young's modulus, as it increases the amount of waste incorporated in the compositions.

4. Conclusions

(a) In this study, it was possible to verify that the use of waste tires in cement blocks for construction is feasible. The use of these waste materials helps the environment by reducing the total mass.

(b) Three types of mixtures were manufactured, with tire waste replacing natural sand. This replacement was 10 %, 15 % and 20 % by mass (wt. %), and tire-free specimens were also manufactured to compare properties.

(c) Water absorption results in percentage, one of the most important properties of building materials, showed that the lowest water absorption rates were presented by samples with tire residue, this behavior is probably due to rubber, as it is an elastomer and has hydrophobic behavior.

(d) According to Brazilian standards NBR 6136:2016, the value of mechanical resistance to compression must be greater than or equal to 3.0 MPa. However, among the blocks surveyed here, the T10 samples were the ones that came closest to this value. It is believed that, with lower levels of waste incorporation (less than 10%), it already meets the technical standards. In addition, it is possible to manufacture solid blocks that are pressed and do not use a firing process.

(e) In analyzing the behavior of stress-strain curves, it was observed that the toughness and the ability to absorb energy were increased. The reference samples suffered a fragile fracture, typical of ceramic materials, while samples with tire residue developed a typical behavior of polymeric materials.

(f) It has been noted that the compressive strength significantly decreases as more tire waste is used. However, the waste material loses the characteristic of fragile material and starts to have a polymeric material behavior.

(g) The values of the modulus of elasticity of tire waste samples are much lower compared to the reference sample modules. This result may be favorable for certain applications when, for example, the material is subject to impact and dynamic loads.

(h) With all the analyses performed in this study, it can be observed that it is possible and feasible to incorporate certain quantities of waste tires, 10%, into concrete blocks for construction. Since these blocks have peculiar characteristics in their properties, which can be useful in certain applications in construction.

According to the results obtained in this research, one comes to the conclusion that use of waste tires waste to manufacture materials for construction is entirely feasible. However, it was observed that to manufacture cement blocks with the same procedure used in this study, it would be necessary to decrease the amount of residue in the composition. But there are possibilities to carry out research to manufacture other types of materials and with other manufacturing processes.

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