

# Development of lightweight concrete from expanded clay modified with tire rubber waste

## Desarrollo de hormigón liviano a partir de arcilla expandida modificada con residuos de caucho

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### Abstract

Lightweight concrete has as main characteristic its low density due to the incorporation of light materials such as expanded clay, or even the incorporation of air whose function is to reduce the density, characteristic of cellular concrete. In Aracaju city, there are companies that promote tire reconditioning, generating large amounts of waste dust. The aim of this work is to study the reuse of tire rubber waste in light concrete from expanded clay. An experimental program was developed for the analysis of these concretes, varying the percentage of 1%, 2.5% and 5% of the tire rubber waste to replace the natural fine aggregate and 100% replacing the natural coarse aggregate by expanded clay (50% of expanded clay C1506 and 50% of C2215). The materials (cement, sand, expanded clays and tire rubber waste) were characterized through tests of particle size analysis and unit mass. The hardened concrete was evaluated through mechanical tests of axial compression strength, modulus of elasticity and tensile strength by diametrical compression, physical tests of water absorption and specific mass, in addition to image analysis by scanning electron microscopy. The use of expanded clay with incorporation of 1% of tire rubber waste guaranteed better results in mechanical resistance, lower water absorption and greater specific mass than the mixtures with 2.5 and 5%, reaching values close to the reference concrete. Thus, the residue can be an alternative for reuse, avoiding disposal.

**Keywords:** Lightweight concrete; expanded clay; tire rubber waste.

### Resumen

El hormigón ligero tiene como característica principal su baja densidad debido a la incorporación de materiales ligeros como la arcilla expandida, o incluso la incorporación de aire cuya función es reducir la densidad, característica del hormigón celular. En la ciudad de Aracaju, existen empresas que promueven el reacondicionamiento de llantas, generando grandes cantidades de polvo de desecho. El objetivo de este trabajo es estudiar la reutilización de residuos de caucho de neumáticos en hormigón ligero a partir de arcilla expandida. Se desarrolló un programa experimental para el análisis de estos hormigones, variando el porcentaje de 1%, 2.5% y 5% de los residuos de caucho de llantas para reemplazar el agregado fino natural y el 100% de reemplazo del agregado grueso natural por arcilla expandida (50% de arcilla expandida C1506 y 50% de C2215). Los materiales (cemento, arena, arcillas expandidas y residuos de caucho de neumáticos) se caracterizaron mediante pruebas de análisis de tamaño de partícula y masa unitaria. El hormigón endurecido se evaluó mediante pruebas mecánicas de resistencia a compresión axial, módulo de elasticidad y resistencia a tracción por compresión diametral, pruebas físicas de absorción de agua y masa específica, además de análisis de imagen por microscopía electrónica de barrido. El uso de arcilla expandida con incorporación del 1% de residuos de caucho de neumáticos garantizó mejores resultados en resistencia mecánica, menor absorción de agua y mayor masa específica que las mezclas con 2,5 y 5%, alcanzando valores cercanos al hormigón de referencia. Por tanto, el residuo puede ser una alternativa de reutilización, evitando su eliminación.

**Palabras clave:** Hormigón ligero; arcilla expandida; residuos de caucho de neumáticos

## 1. Introduction

Conventional concrete produced from Portland cement and natural aggregates (sand and gravel) is the most used in civil construction around the world, due to the ease of finding its components and its application being adaptable to any condition. Since the 1970s, concrete has been known as a simple mixture of cement, aggregates, and water. After technological advances, there has been a great evolution of this material, incorporating new techniques and equipment for the study of concrete (Rossignolo, 2009).

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One of these technological advances was the emergence of concrete with artificial lightweight aggregates (expanded clay), characterized as a type of concrete widely used in civil construction due to its low specific mass between 300 and 900 kg/m<sup>3</sup> and high levels of mechanical strength, reaching 50MPa (Rossignolo, 2009), being applied for structural, non-structural, and sealing purposes (Bogas, 2012).

According to (Mehta, 1994), the introduction of light aggregates to cement matrices makes possible to obtain light concrete with a specific weight of about 1600 kg/m<sup>3</sup> and compressive strength between 25 and 40 MPa. In addition, expanded clay is characterized by its good resistance to fire and aggressive environments, good thermal and acoustic insulator, glassy and rigid surface, and high level of water absorption. So, it has been the object of research as an alternative to replace conventional aggregates without compromising the mechanical strength of concrete (Borja, 2011); (Pereira, 2012); (Abreu, 2014).

In recent times, the concern with sustainability has led civil construction sector to develop new research, aiming to create alternative sources of raw materials, which resulted in the reuse of tire rubber waste in concrete (Pczieczek, 2017).

For (Fioriti, 2007), the use of tire rubber waste from retreading brings a series of benefits, such as the reduction in the volume of waste that can cause health problems and environmental degradation, optimization of landfills useful life, consumption reduction of aggregates natural sources used in the production of concrete, and reduction in the emission of pollutants into the atmosphere provoked by the material burning.

According to (Giacobre, 2008), tire waste presents a very slow decomposition and low compressibility, which results in the occupation of large spaces for storage. Its burning causes the so-called black smoke, which is highly polluting due to the diversity of compounds released during combustion, causing damage to health, and the oily material, derived from petroleum, which is conducted to water bodies, contaminating them, and making them unfit for consumption. The use of waste tires appears as an alternative for the disposal of waste tires, being an innovative option that would bring environmental, economic and performance benefits to concrete (Angelin, 2016).

According to the (ANIP, 2018), around 50 million new tires are produced annually in Brazil, and only 26.5% have an environmentally adequate and regulated destination. According to (Boaventura, 2011), the use of waste tires has been applied in civil construction to produce concrete, asphalt paving, curbs, among others, which ensures a reduction in the extraction of natural resources to produce these artifacts.

In this research, the aim was to investigate the influence on the technological properties of tire rubber waste when incorporated into lightweight concrete produced with expanded clay. The incorporation of tire rubber waste in the formulation helps to reduce the weight of the structure due to the drop in density, as it reduces the environmental impact caused by disposal or even transforms the waste into an option for reuse in civil construction.

## 2. Materials and methods

### 2.1 Material

The materials used in the production of lightweight concrete were Portland cement type CP II-F-32, natural sand from the municipality of Estância/SE, tire rubber waste from the tire retreading process of Sergityres Industrial, from municipality of Nossa Senhora do Socorro/SE, two expanded clay granulometries (C1506 and C2215), produced by Cinexpan Company, located in São Paulo/SP, water supply system in the city of Estância/SE, silica fume brand Ferbasa and Type II superplasticizer additive from Matchem brand, model Maxifluid PX 1185.

Granulometry determination of the aggregates was performed according to NBR NM 248/2003, and their classifications were determined according to NBR 7211/2009. The unit masses and bulk density dry masses of fine aggregate and tire rubber waste were determined in accordance with NBR 9776/1988. For expanded clays, the unit mass was determined according to NBR NM 45/2006. The bulk specific gravity of cement was determined according to NBR 16605/2017. The materials characterizations results are shown in (Table 1). As expected, the tire has a specific mass and unit mass much lower than the other materials, which should contribute to the reduction of concrete density.



**Table 1.** Physical characterization of raw materials used in concrete.

RAW MATERIAL	BULK SPECIFIC GRAVITY (g/cm <sup>3</sup> )	BULK DENSITY DRY (g/cm <sup>3</sup> )	MAXIMUM DIAMETER (mm)	FINESS MODULUS
Cement	3,27	-	-	-
Sand	2,59	1,52	4,75	2,32
Expanded	2,55	0,66	19,00	2,65
Expanded	2,64	0,52	25,00	3,22
Waste rubber tire	1,18	0,38	1,18	2,16

Source (Own autor, 2021)

## 2.2 Methods

The methodology used to calculate the formulations was the dosage method adapted from the BAPC (Brazilian Association of Portland Cement) to produce both concrete with expanded clay and concrete with the addition of tire rubber waste. Four formulations were established: the reference one, without the addition of tire rubber residue, and other three formulations, with the replacement of 1%, 2.5% and 5% of the sand by tire rubber residue. We opted for these formulations since in other studies (Angelin,2016); (Angelin, 2108), the strength of concrete with incorporated rubber has already decreased with 5 to 9% of rubber. In addition, 10% of silica fume was added in relation to the weight of cement in the mixtures with rubber residue, and 0.5% of superplasticizer in all concrete mixtures. The dosages of materials are shown in (Table 2).

According to the author (Angelin, 2016), it is recommended to add 10% of silica fume in relation to the weight of cement in the mixtures with rubber residue, to improve adhesion and transition zone between cement paste and aggregate, increasing mechanical resistance. Also, adding 0.5% of superplasticizer favors the workability. In this research, initial tests were carried out with a single diameter of expanded clay (C2215) with a maximum diameter of 25 mm, replacing the natural coarse aggregate. It was found that with its use, many voids were formed between the grains, which would compromise the strength of the concrete. Therefore, the use of a particle size immediately smaller than the one used (C1506) with a maximum diameter of 19 mm was adopted, so that this problem could be minimized. Consequently, it was used 50% of C1506 and 50% of C2215.

**Table 2.** Concrete formulation (kg/m3)

RAW MATERIALS	FORMULATIONS			
	STD	1%	2,5%	5%
Cemente	1,00	1,00	1,00	1,00
Sand	3,12	3,09	3,04	2,96
Expanded clay C1506	0,53	0,53	0,53	0,53
Expanded clay C2215	0,43	0,43	0,43	0,43
Ruber waste tire	-	0,03	0,08	0,16
Relation a/c	0,50	0,50	0,50	0,50
Active silica (%)	-	10	10	10
Susperplasticizer (%)	0,5	0,5	0,5	0,5

Source (Own autor, 2021)



### 2.3 Concrete molding and curing

The materials were mixed in a concrete mixer with a capacity of 200 L. For the reference concrete, 50% of cement, sand, expanded clay (C1506 and C2215) and water were first introduced, mixed for 3 minutes. The other 50% of the materials were placed right away and mixed for another 3 minutes. Lastly, the superplasticizer was added, and the materials were mixed for another 5 minutes. For concrete with tire rubber waste, 50% of each material was placed in the concrete mixer and mixed for 3 minutes. Then, the remaining 50% of the materials, including all the silica fume, were added, and mixed for another 3 minutes.

The superplasticizer was added at the end and mixed for another 5 minutes before molding the specimens, according to the NBR NM 67/1998. For each concrete mixture, 15 cylindrical specimens with 10 cm of diameter and 20 cm of height were molded for physical and mechanical tests. After 24 hours of initial curing, the specimens were demolded and submitted to the curing process by immersion in water. For the molding and curing of the specimens, the recommendations of standard NBR 5738/2016 were followed.

### 2.4 Concrete characterization

For the characterization of the concretes, the following tests were carried out: i) slumping of the cone trunk by NBR NM 67/1998 to verify the workability and consistency of fresh concrete; ii) water absorption and specific mass with 28 days of concrete curing according to NBR 9778/2009 ; iii) axial compressive strength of concrete with 28 days of cure according to NBR 5739/2019 ; iv) modulus of elasticity for concretes with 28 days of cure according to NBR 8522/2017; v) tensile strength by diametrical compression for concretes with 28 days of cure according to NBR 7222/2011. Micrographs were obtained using a scanning electron microscope JEOL JSM 5700. The samples were metallized with gold and fixed to a carbon tape for the fracture surface analysis.

## 3. Results

The slump of the cone trunk results varied around  $(10.5 \pm 2.0)$  cm referring to the mean of the samples (reference one and with tire rubber residue).

(Table 3) presents the results of water absorption and specific mass for all formulations. The mean results and standard deviations were analyzed using the ONE-WAY ANOVA statistical method, showing that they are not significant, being able to state that the variations are equal with a 95% confidence level. A tendency to increase water absorption values was observed when there is the incorporation of tire rubber waste in concrete in relation to light reference concrete. According to (Angelin, 2018), this happens due the fact that rubber has a hydrophobic nature and a rough surface, which increases the volume of voids.

Note that there was a reduction in specific mass with the replacement of fine aggregate by tire rubber waste in relation to lightweight concrete containing only expanded clay. The explanation is that rubber has a specific mass  $(1.18 \text{ g/cm}^3)$  lower than sand  $(2.59 \text{ g/cm}^3)$ . Since it is less dense, it will take up less space, and consequently, it will reduce the concrete weight.

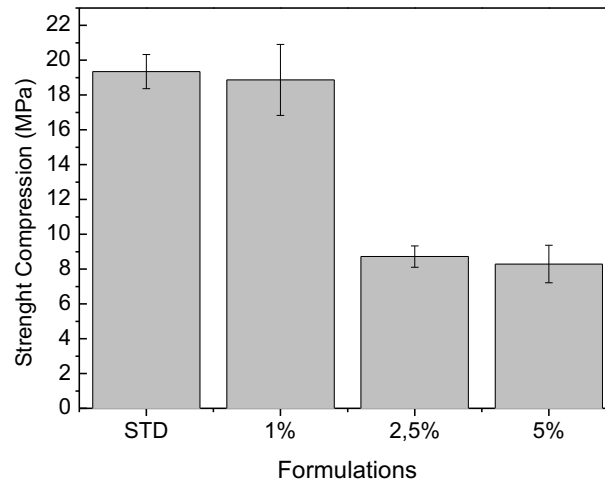
**Table 3.** Water absorption and specific mass of hardened concrete

CONCRETE	CHARACTERIZATION TESTS	
	Water Absorption (%)	Bulk Density dry (kg/m <sup>3</sup> )
STD	7,69 ± 0,15	1680 ± 30
1%	8,28 ± 0,25	1577 ± 31
2,5%	9,55 ± 1,44	1280 ± 40
5%	11,69 ± 1,69	1277 ± 15

Source (Own autor, 2021)

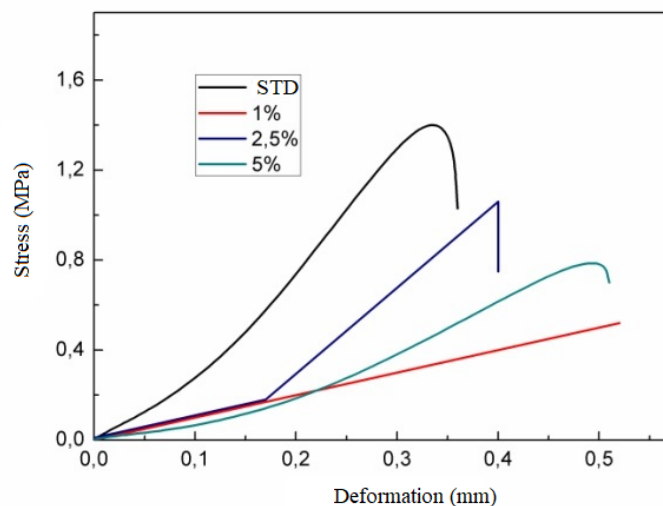


The results of axial compressive strength are shown in (Figure 1). The reference lightweight concrete was the one with the highest values of axial compressive strength at 28 days. From the partial replacement of fine natural aggregate by rubber residue, there was a decrease in strength values, which according to previous works, was expected to show this decrease in concrete strength (Santos, 2005); (Freitas, 2007). However, concrete can be used in the production of non-structural parts such as sewer boards and adornment in general (Bogas, 2012).



**Figure 1.** Strength to axial compression at 28 days of cure  
 Source (Own autor, 2021)

(Figure 2) shows the stress-strain curve for the axial compressive strength, in which the post-peak abrupt rupture was verified in the reference concrete, which shows its fragility. In mixtures with tire rubber waste, the graph shows that after the load is applied to the concrete, it presents a slight increase in deformation in relation to the reference concrete due to the rubber being an artificial polymer, presenting a ductile behavior. In his research, (Santos, 2005) analyzed concrete with tire rubber waste, in which it presented a smooth rupture in the descending branch of the stress-strain curve, different from conventional concrete, which presented sudden rupture.

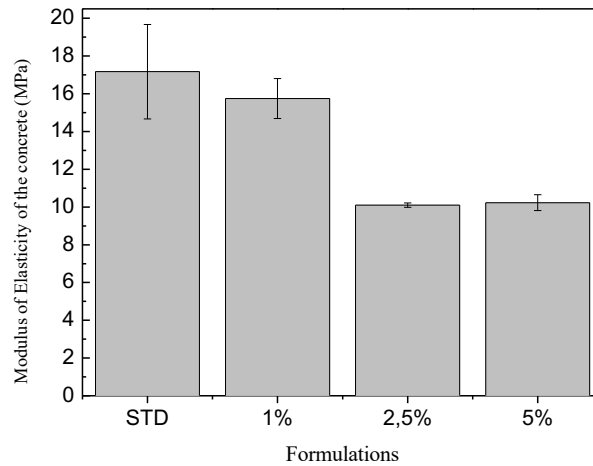


**Figure 2.** Stress x deformation curves of concrete at 28 days of hydration  
 Source (Own autor, 2021)



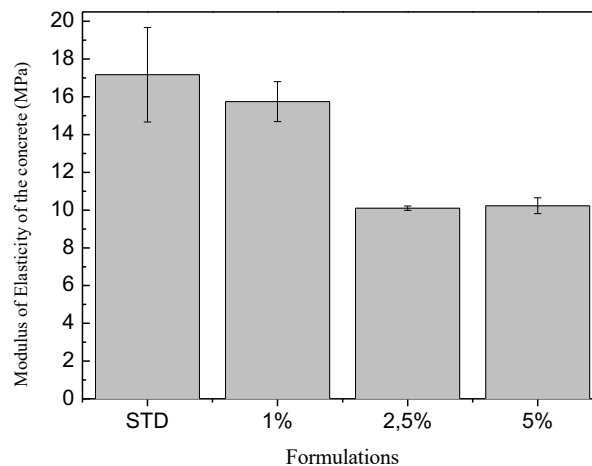
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(Figure 3) shows the average data from the modulus of elasticity test, at 28 days, with the produced formulations. The highest value of modulus of elasticity found was the reference concrete, favored by the fact that this concrete has only expanded clay in its composition, which ensured greater rigidity. By adding fewer rigid particles, such as tire rubber residue, the modulus is smaller in the region of elastic deformation. In the research by (Ling, 2012), in which 5 and 20% of sand were replaced by tire rubber residue, he obtained a reduction of 17 and 56.8%, respectively, in the modulus of deformation in relation to the reference concrete. It proved that increasing the tire rubber residue content implied in decreasing the concrete's modulus of elasticity.



**Figure 3.** Modulus of elasticity of the concrete at 28 days of age  
Source (Own autor, 2021)

(Figure 4) shows the values resulting from the tensile strength test by diametrical compression for each mix. As in the results of the axial compression strength test, it was possible to observe that there was a decrease in the tensile strength by diametrical compression in lightweight concretes with rubber residue in relation to the reference lightweight concrete. Authors such as (Freitas, 2007); (Ling, 2011); (Ling, 2012); (Yung, 2012) also observed this decrease in resistance when tire rubber residue was added. The results obtained agree with the expected, since in works carried out with replacement of sand by tire rubber residue in concrete and mortars, they showed a decrease in mechanical strength with the increase in the amount of this residue (Silva et al, 2016); (Ling, 2012).



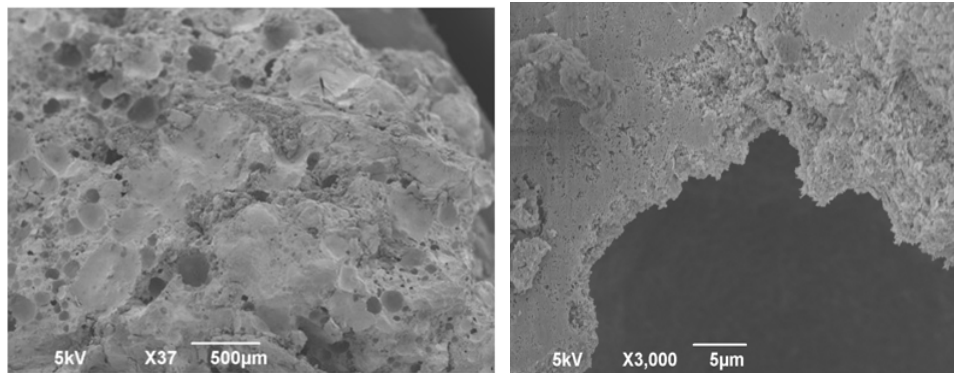
**Figure 4.** Tensile strength by diametrical compression of concrete at 28 days cure  
Source (Own autor, 2021)





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(Figure 5a) and (Figure 5b) shows a Scanning Electron Microscopy (SEM) image of the fracture surface of concrete containing 5% of rubber, in which the presence of rubber in the mixture can be observed, in addition to revealing agglomeration of irregularly shaped particles and varied sizes.



**Figure 5a.** Surface micrograph

**Figure 5b.** Surface micrograph

Source (Own autor, 2021)

## 4. Conclusions

In this research, it was possible to produce lightweight concretes using two types of expanded clay particle sizes, C1506 and C2215, and lightweight expanded clay concretes with partial replacement of the fine natural aggregate by 1, 2.5 and 5% tire rubber waste. The reference concrete showed lower water absorption and higher specific mass. It was found that the greater the incorporation of tire rubber residue in the concrete, the greater was the absorption of water by immersion and the lower was its specific mass.

With the results of both axial compressive strength and tensile strength tests by diametrical compression, it was found that the greater the incorporation of rubber residue in the concrete resulted in a decrease in mechanical strength.

The results of the modulus of elasticity of the reference concrete showed that it presents itself as a more rigid material when compared to the other mixtures with 1, 2.5 and 5% of tire rubber waste. The mixtures with rubber residue showed a post-peak deformation, without sudden rupture as happened with the reference concrete, since rubber is a polymeric material with ductile behavior.

With these data, the use of rubber waste in partial replacement of the fine natural aggregate, causes changes in the behavior of the concrete. However, even with the reduced values of strength in relation to the reference concrete, its use would be viable and can be applied for purposes non-structural, being a viable alternative from an environmental point of view and in terms of sustainable and economic performance. Furthermore, reuse can offer a way of using this type of waste.

## 5. Acknowledgments

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