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Artículo Original

Analysis of the incorporation of waste rubber from waste tires as fine partial aggregate in concrete

Análisis de la incorporación de caucho de desecho de llantas de desecho como agregado parcial fino en el hormigón

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Resumen

La producción mundial de neumáticos crece debido al aumento de la industria del automóvil, y es muy difícil deshacerse de los neumáticos de desecho a medida que disminuye la disponibilidad y la capacidad de los vertederos. Por lo tanto, el objetivo principal de este estudio es evaluar el comportamiento del hormigón con la sustitución de áridos finos por residuos de caucho de llantas de desecho. Se realizó un estudio de la dosificación y moldeado de las probetas en las dimensiones de 10 x 20 cm, con reposición del agregado fino (arena de cuarzo) por 10 y 20 % de residuos de caucho, y se evaluaron las propiedades del hormigón. mediante las pruebas de Resistencia a la compresión simple, Resistencia a la tracción por compresión diametral y Determinación de la absorción de agua. Los resultados permitieron concluir que la sustitución del árido fino convencional por residuos de caucho promovió una reducción de la resistencia a la compresión y tracción del hormigón y un aumento de la absorción de agua. Por tanto, es necesario un tratamiento de estos residuos, ya que la modificación del hormigón con residuos de caucho de neumáticos sin tratamiento previo proporcionó importantes pérdidas de resistencia.

Palavras-chave: Áridos reciclados, caucho para neumáticos, hormigón, medio ambiente, reciclaje

Abstract

The worldwide production of tires grows due to the increase in the automobile industry, and it is tough to dispose of waste tires as the availability and capacity of landfills decreases. Therefore, the main objective of this study is to evaluate the performance of concrete with the replacement of fine aggregate by rubber waste from waste tires. Therefore, a study of the dosage and molding of the specimens in the dimensions of 10 x 20 cm was carried out, with replacement of the fine aggregate (quartz sand) by 10 and 20 % of rubber residues, and the properties of the concrete were evaluated by through the tests of Compression Strength, Tensile Strength by Diametral Compression, and Determination of Water Absorption. The results allowed us to conclude that the replacement of conventional fine aggregate by rubber residues promoted a reduction in the compressive and tensile strength of concrete and increased water absorption. Therefore, treatment of these residues is necessary since the concrete modification with tire rubber residues without prior treatment provided a significant loss in strength.

Keywords: Recycled aggregates, tire rubber, concrete, environment, recycling

1. Introduction

Concrete is the most widely used material globally and one of the primary composite materials for construction [1-4]. Sustainable concrete is one of the essential concretes for the current scenario [5]. Neglecting the broader consequences of economic development has led to a global environmental crisis fueled in part by wasted material resources [6].

The high consumption of materials due to industrial development has led to the depletion of natural resources, including energy and raw materials. Additionally, a significant amount of waste arises with the growth of production, and the waste negatively impacts the environment [7]. For example, the rise of the automobile industry leads to the production of a vast amount of waste tires worldwide. Consequently, disposal of waste tires continues to pose a serious threat to environmental protection and health [8].

Rajan, Sakthieswaran, and Babu [5] point out that 75 to 80 % of waste tires are buried in landfills. Investigations have shown that scrap rubber tires contain materials that do not decompose under environmental conditions and cause serious problems. The recycling of waste tire rubber incorporating it into concrete has become a good solution for the disposal of waste tires. The mechanical and durability properties of concrete with waste rubber tires with different replacement forms and volume contents were investigated.

Bisht and Ramana [9] investigated the mechanical and durability properties for the proportions of 4, 4.5, 5, and 5.5 % of tire rubber waste added to concrete. The results showed that the tensile and compressive strengths decreased with the increase of 4 %. Abdullah et al. [10] investigated the effects of partial sand replacements by residual fine rubber on long-term concrete performance under low impact midpoint bending loading. The samples were prepared with 5 and 10 % replacement by volume about sand. The authors observed a reduction in compressive strength and flexural strength as the tire rubber residue content increased. The studies corroborate what was found by Ganjian et al. [11] in which they incorporated the contents of 5%, 7.5%, and 10% of tire rubber in concrete.

Rajan, Sakthieswaran, and Babu [5] performed a study with the addition of 2.5, 5, 7.5, and 10 % of tire rubber waste added to 5 % sodium hydroxide, then added to the solution of potassium permanganate and finally soaked in a saturated solution of sodium bisulfate at 60°C for 1 hour. The results showed that the strength increased with modified rubber residues and that concrete absorption decreased with the increase in added content.

Thus, the following question emerges the need for studies investigating the use of waste from other industries in materials for use in civil construction. Based on the above, this study seeks to evaluate the properties of concrete with the addition of waste tire rubber at levels of 10 and 20 % in replacement of fine aggregate to analyze the influence of adding values more significant than those commonly used in the literature.

2. Materials and Methods

This section describes the materials and procedures performed during the experimental phase of the research, following the standards of the Brazilian Association of Technical Norms (ABNT).

Materials

In the concrete production in this study, Portland cement CP II Z 32 was used, compounded with the addition of pozzolan, acquired in the local commerce of the Campina Grande-PB city. The fine aggregate used was quartz sand extracted from Paraíba River-PB.

The coarse aggregates, 25 mm gravel and 9.5 mm gravel, were provided by the company Rocha Cavalcante, located in the municipality of Campina Grande-PB. The water used was water supplied by the Water and Sewage Company of Paraíba (CAGEPA), potable and intended for human consumption. The waste tire rubber (WTR) was supplied by LBFlex Borrachas, located in Campina Grande-PB. The rubber was used as received from the supplier, with no treatment being carried out that could change its properties, as shown in Figure 1.

Fig.1 WTR used in the production of concrete

Figure 2 shows the particle size distribution of the aggregates, tested according to the ABNT NBR NM 248:2003 standard, and Table 1 shows the results of the physical characterization of the aggregates.

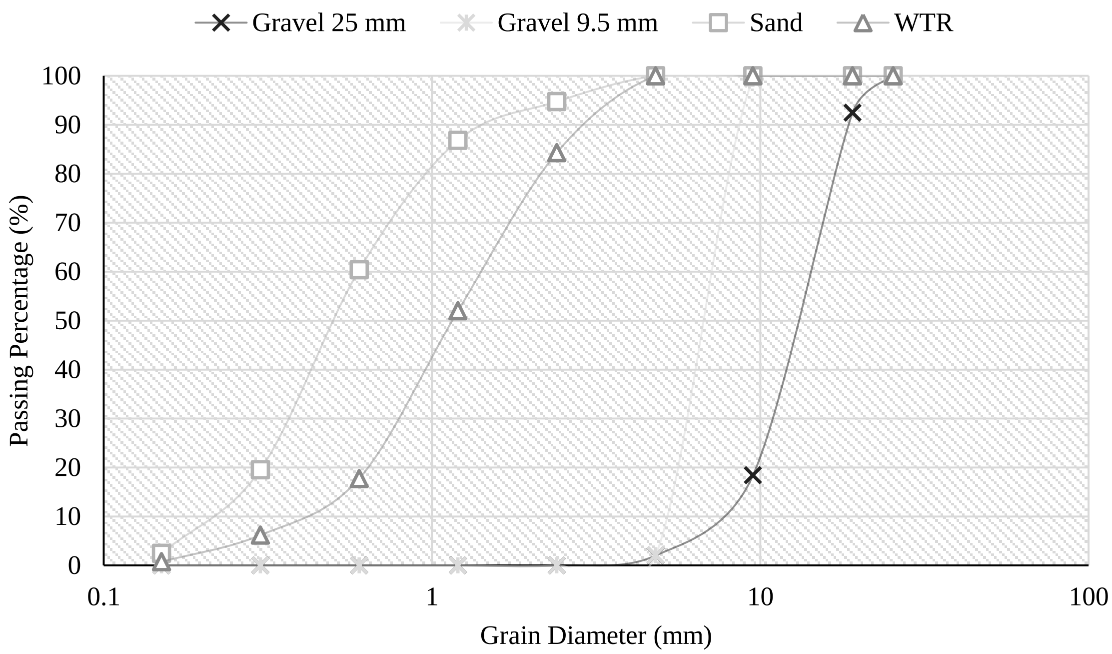

Fig.2 Particle size distribution of aggregates

Table 1. Physical characterization of materials

Tests	Results					Standard
	Gravel 25 mm	Gravel 9.5 mm	WTR	Sand	Cement	
Real specific mass (g/cm³)	2.690	2.680	0.670	2.590	2.910	ABNT NBR 16917:2021/ ABNT NBR 16916:2021
Absorption (%)	0.3	0.5	52	-	-	ABNT NBR 16917:2021
Unit mass in loose state (g/cm³)	1.5	1.43	-	1.5	-	ABNT NBR NM 45:2006
Fineness index (%)	6.87	5.98	-	2.37	2.84	ABNT NBR NM 248:2003
Powder Material Content (%)	-	-	-	0.07	-	ABNT NBR NM 46:2003
Nominal maximum diameter (mm)	25	9.5	2.36	2.36	-	ABNT NBR NM 248:2003

It is verified that the coarse aggregates presented a specific mass value equal to 2.69 g/cm³ and 2.68g/cm³, with the absorption of 0.3 and 0.5 %, respectively. According to Metha and Monteiro [12], the specific mass of the coarse aggregate is on average 2.7g/cm³, so that the value obtained in the research fits into this specification. Furthermore, Chagas Filho [13] points out that the absorption value of granitic aggregates is approximately 0.3 % so that the results obtained were satisfactory.

For the specific mass of the fine aggregate, the value of 2.59g/cm³ was obtained, and for the unit mass, the value of 1.50g/cm³, similar to the values found [14]. It is observed that the absorption of waste rubber from tires is significantly higher than the absorption obtained for natural aggregates, which directly influences the performance of the mixture. According to ABNT NBR NM 248:2003, the limit value for cement fineness is 12 %, so that the result obtained in this study meets the established limit. In Brazil, the cement produced has a specific mass of 2.90 to 3.20g/cm³; the value obtained for research is in this range.

Dosage study

For concrete dosage, the method used was that of the Brazilian Association of Portland Cement (ABCP), and, after the characterization of the materials, the mixture 1:2:3.14 was obtained, with a water/cement factor (w/c) of 0.65. The choice of replacement percentages of fine aggregate by waste rubber from waste tires was 10 and 20 %, determined from information extracted from previous research [5, 9-11] on the subject, in order to assess the influence the addition of values higher than the levels commonly used in research.

The mix adopted as a reference has a characteristic strength (fck) of 20 MPa and a cement consumption of 4.5 kg/m³. Therefore, the slump test value was set between (40 - 60 mm); however, after performing the test, as recommended in ABNT NBR 16889:2020, it was noted that to obtain the desired slump value, an increase in the amount of water would be necessary, thus obtaining the corrected mix of 1:2:3.14:0.67 for concrete with the addition of 10 % of rubber residues and 1:2:3.14:0.70 for the concrete with the addition of 20 % of rubber waste.

Sequentially, reference cylindrical specimens (CREF) were molded with dimensions of 10 cm in radius and 20 cm in height, and specimens with replacement of the fine aggregate by waste rubber from waste tires, in the proportion of 10 and 20 % being named C10%WTR and C20%WTR, respectively, and the curing ages for breaking the specimens of 7, 14, 21 and 28 days were established. To carry out the tests established in the research, 72 specimens were molded. Table 2 represents the consumption of materials used to make the research specimens.

Table 2. Consumption of materials for making the specimens

Material	CREF	C10%WTR	C20%WTR
Cement (kg)	12.85	12.75	12.62
Sand (kg)	25.7	22.95	20.19
Gravel 9.5mm (kg)	16.14	16.00	15.85
Gravel 25.0 mm (kg)	24.21	24.00	23.78
Water (L)	8.35	8.55	8.83
WTR (kg)	0	2.55	5.05

The proportion between coarse aggregates was established following the ABNT NBR NM 45:2006 standard, according to the proportions 70/30, 60/40, and 50/50, respectively, the proportion of 60 % for gravel 25 40 % for gravel 9.5, was chosen for having the most enormous unitary compacted mass. The molding of the specimens was performed by ABNT NBR 5738: 2015 (Concrete - Procedure for molding and curing of specimens). After molding, the specimens were placed in a protected location, on a horizontal and vibration-free surface, for an initial period of 24 hours. Then, immersed curing was carried out in a specific curing tank for concrete, where the specimens remained until the day scheduled for the tests, as shown in Figure 3.

Fig.3 Specimens immersed in water

Determination of the properties of the concrete understudy

The determination of absorption was carried out according to the ABNT NBR 9778:2005 standard. This test expresses as a percentage the increase in mass of a porous solid body due to water penetration in its permeable pores. The simple compressive strength test to perform the mechanical characterization of concrete was carried out according to ABNT NBR 5739:2018. The specimens were previously corrected to promote a flat surface free of undulations, as established in ABNT NBR 5738:2015.

The determination of indirect tensile strength was performed to obtain the fct, sp, and the test followed the ABNT NBR 7222:2011 standard. The number of specimens kept the same quantity for the simple compression and absorption resistance test, the value of 24 specimens. Two specimens of each concrete mixture (CREF, C10%WTR, and C20%WTR) were used for each curing time determined in the study (7, 14, 21, and 28 days), totaling 72 tested specimens.

3. Results and Discussion

This section presents and discusses the results obtained in the experimental phase of concrete specimens with waste rubber from waste tires.

Compression Strength

Figure 4 shows the results obtained for the simple compressive strength of reference concrete - CREF, concrete with 10 % waste rubber from waste tires - C10%WTR and concrete with 20% rubber waste tires - C20 %WTR.

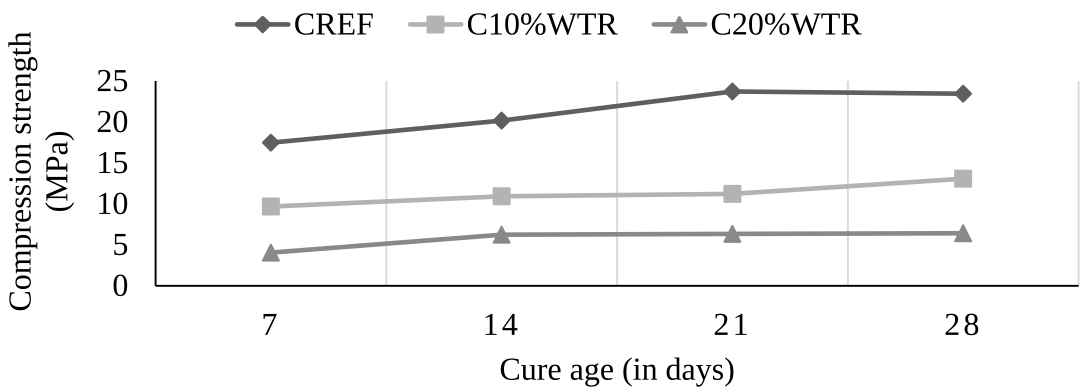

Fig.4 Results of the compressive strength test of concrete

According to the results obtained, it is verified that replacing the conventional fine aggregate (quartz sand) with tire rubber waste in the contents of 10 and 20 % promoted the reduction of the simple compressive strength of concrete for all ages cure under study. Concrete with 10 % incorporation of tire rubber waste showed a reduction of the order of 44.7 % for 7 days of cure, 45.8 % for 14 days of cure, 52.7 % for 21 days of cure, and 44.2 % for 28 days of cure. The decrease in strength in concrete with 20 % of residues was more significant, with a loss of 76.8 % for 7 days of cure, 69 % for 14 days of cure, 73.3 % for 21 days of cure, and 72.6 % for 28 days of cure. Thus, using these residues as a replacement for conventional fine aggregate compromises the strength of concrete, not meeting the requirements of ABNT NBR 6118:2014, which establishes a minimum strength for concrete at 28 days 20MPa.

With the performance of t-tests, this result was confirmed to a significance of 5%. Samples with replacement of conventional fine aggregate by tire rubber waste at 10% (C10%WTR) presented p-value of $7.16x10^{-12}$, $3.64x10^{-12}$, $1.09x10^{-12}$, and $2.29 x10^{-12}$, respectively, for 7, 14, 21, and 28 days of cure. By analyzing the 20% content, in the replacement of fine aggregate by tire rubber waste (C20%WTR), a similar result was obtained; the value found was $8.22x10^{-13}$, $7.08x10^{-13}$, $2.91x10^{-13}$, and $3.16x10^{-13}$, respectively for 7, 14, 21, and 28 days of cure. Thus, the null hypothesis that there are no statistically significant differences between the samples for all tests performed is rejected, as they presented a p-value below the significance of 0.05, which verifies the significant reduction in strength with the use of residues. Furthermore, there are no significant variations in the p-value between samples about the variation in days of cure.

Selung et al. [15] observed in their study that there was a significant reduction in compressive strength in concrete with a rubber residue content of up to 25 %, remaining practically constant up to 35 % of residue addition. According to the authors, the drop in traits with incorporation of up to 25 % can reach 88 %. Granzotto [16] obtained a reduction of 39 % for the addition of 10 % of rubber residue in his study. Literature analysis shows that the mechanical properties of concrete incorporated with WTR are influenced by particle size composition, residue origin, previous surface treatment of the residue, and the use of plasticizer additives, which can be obtained for the same content. Of incorporated residue, different values of mechanical resistance. Ganjian et al. [11] and Seydell and Lints [17] also observed loss of compressive strength for concrete with tire rubber.

The study by Rajan, Sakthieswaran, and Babu [5] showed strength gain in concrete modified with tire rubber, but the waste treatment process explains this gain before incorporation into concrete.

Tensile Strength by Diametral Compression

Figure 5 shows the results obtained for the tensile strength by diametrical compression of reference concrete - CREF, concrete with 10 % waste rubber from waste tires - C10%WTR, and concrete with 20 % rubber waste tires unserviceable – C20%WTR.

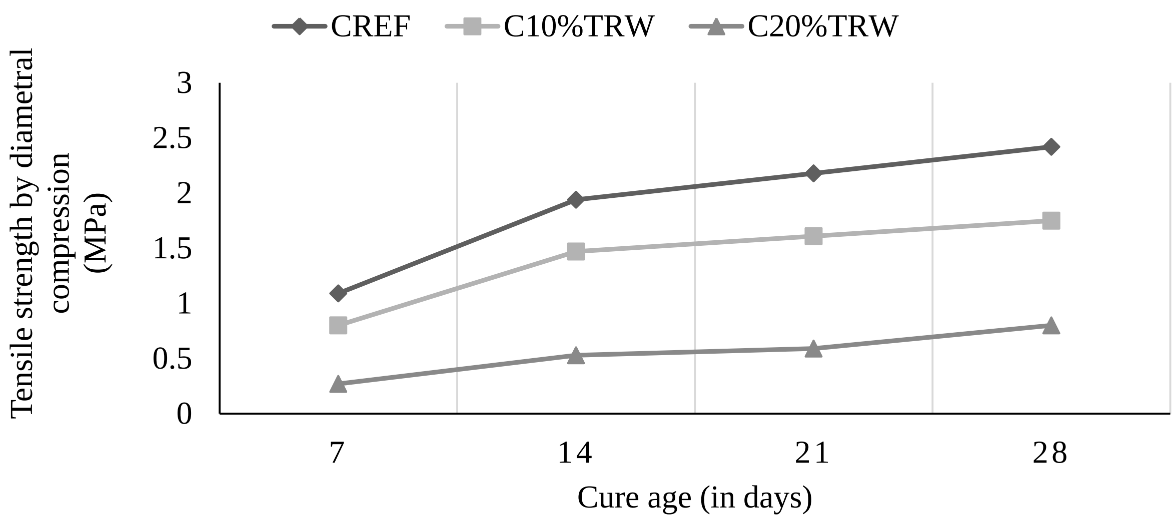

Fig.5 Results of the tensile strength test by diametrical compression of concretes

According to the data obtained in Figure 5, it is verified that the tensile strength by diametrical compression of concretes with the incorporation of 10 and 20 % of tire rubber waste showed a reduction compared to the strength obtained for the reference concrete, similar to that observed for the simple compressive strength, being, however, less significant. For the concrete with the addition of 10 % of residue, there was a reduction of the order of 26.6 % for the age of 7 days, 24.2 % for the age of 14 days, 26.1 % for the age of 21 days, and 27.7 % for the age of 28 days.

The strength losses for concrete with the addition of 20 % of residue were more significant with 75.2 % for the 7-day curing age, 72.6 % for the 14-day curing age, 72.9 % for the 21-day curing age, and 66.9 % for the healing age of 28 days. It is noteworthy that the strength losses obtained for the 20 % grade were three times greater than the values obtained for tensile strength by diametrical compression for concrete with 10 % residue incorporation.

The results obtained were analyzed using t-tests for a significance of 5%. Samples with replacement of conventional fine aggregate by tire rubber waste at 10% (C10%WTR) presented p-value of 0.0075, 5.45×10^{-7}, 2.52×10^{-7}, and 1.32×10^{-7}, respectively to 7. 14, 21, and 28 days. A similar result was obtained for the C20%WTR samples, corresponding to the replacement of fine aggregate by tire rubber waste at 20% content; the value found was 5.89×10^{-8}, 6.74×10^{-9}, 4.17×10^{-9}, and 9.79×10^{-6}, respectively for 7, 14, 21, and 28 days. Thus, the null hypothesis that there are no statistically significant differences between the samples for all tests performed is rejected, as they presented a p-value below the significance of 0.05. This result verifies the significant loss of resistance using tire rubber residues for all studied samples.

For Giacobbe [18], the reduction in the mechanical properties of concrete produced with tire rubber waste can be attributed to the difficulty of densifying materials with smaller particle sizes, which contribute to the segregation of the mixture due to the ease of displacement within the mass.

Albuquerque [19] reports that although there is a reduction in mechanical properties, the same concrete demonstrates a greater capacity for deformation and has a less fragile behavior to fracture, indicating a greater capacity for energy absorption than conventional concrete. According to the author, the behavior of the mixture is due to the performance characteristics of tire rubber, which is capable of withstanding large elastic deformations before the concrete fractures. This feature is exciting and has applicability in situations where concrete is subject to cracking. However, as observed when breaking the specimens by diametrical compression, with the increased content of incorporated residue, despite the reduction in mechanical properties, the specimens presented more minor cracks. They required an additional effort to divide them in half, a phenomenon observed for the specimens with 20 % of waste incorporated, as shown in Figure 6.

Fig.6 Cracks in the specimen for concrete with 20% incorporated content

Determination of water absorption

Figure 7 shows the results obtained for the water absorption obtained for the reference concrete - CREF, for the concrete with tire rubber residues in the contents of 10% - C10%WTR, and the concrete with 20% - C20%WTR.

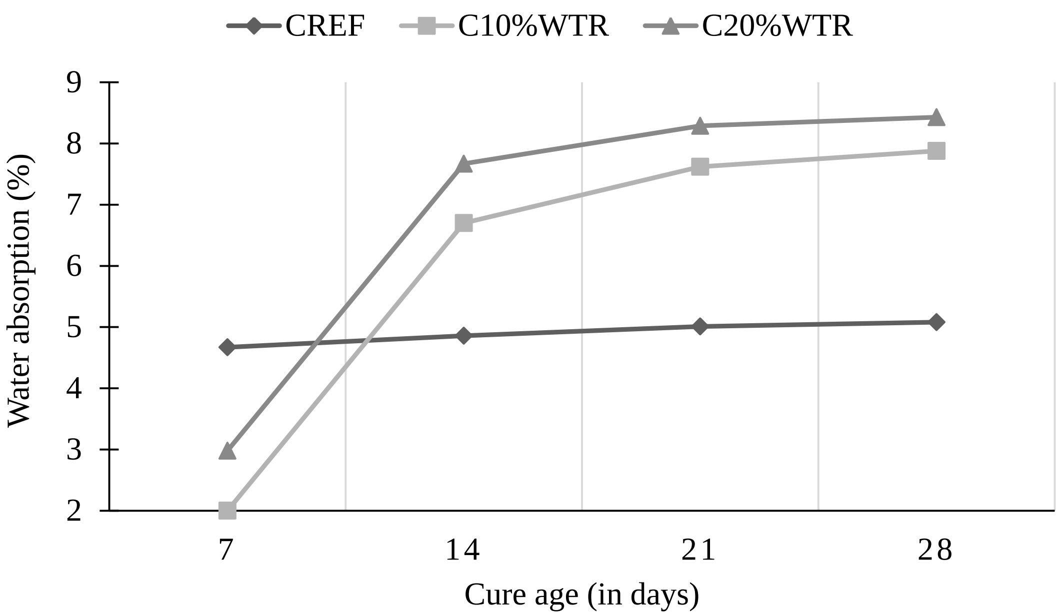

Fig.7 Concrete water absorption results

For the values found, it can be noted that there was a large dispersion of data. For example, the concrete C10%WTR presented at 28 days an absorption of 55.12 % higher than the CREF; the C20%WTR achieved an absorption 65.95 % higher than the reference.

Selung et al. [15], when conducting the absorption tests on concrete blocks incorporated with tire rubber, they verified the increase in absorption as the rubber content increased. However, Fioriti et al. [20] reported that the use of waste rubber from tires does not significantly interfere with the water absorption of concrete.

Rajan, Sakthieswaran, and Babu [5] point out that the water absorption of concrete decreased with the addition of 10 % of tire rubber, reinforcing the fact that the waste used by the authors went through a treatment process before being incorporated into the concrete.

For this study, the results obtained were analyzed using t-tests, performed pair by pair, with a significance of 5%. Samples with replacement of conventional fine aggregate by tire rubber waste at 10 % (C10%WTR) presented p values of $5.25x10^{-10}$, $3.43x10^{-5}$, $5.75x10^{-10}$, and $4.34x10^{-10}$, respectively, for 7, 14, 21, and 28 days. For samples with replacement of fine aggregate by tire rubber residues at 20 % content (C20%WTR), the value found was $3.27x10^{-9}$, $4.28x10^{-10}$, $2.30x10^{-10}$, and $2.12x10^{-10}$, respectively, for 7, 14, 21, and 28 days. Based on these results, the null hypothesis that there are no statistically significant differences was rejected for all tests performed, as they presented a p-value below the significance of 0.05. Thus, there is a significant influence on water absorption from the replacement of fine aggregate by tire rubber residues for all samples studied. In addition, there was a reduction at 7 days and a significant increase for the other healing ages studied.

4. Conclusion

The replacement of conventional fine aggregate by these residues provided the concrete with a lower performance in terms of simple compressive strength and tensile strength than that obtained for the reference concrete. Using these residues as a replacement for conventional fine aggregate compromises the strength of concrete, not meeting the minimum strength recommended by the standard. Although there was a reduction in mechanical properties, the same concrete demonstrates a greater capacity for deformation and has a less fragile behavior to fracture, indicating a greater capacity for energy absorption than conventional concrete. The presence of tire rubber caused an increase in absorption for the two contents tested. Therefore, the addition of high-grade tire rubber residues to concrete is not indicated without a previous treatment of the residues since the modification of the concrete provided significant losses in strength. Studies with tire rubber waste treatment processes for use in structural concrete should be encouraged since recycling reduces the environmental impact caused by a large amount of waste generation.

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Conflict of Interests

No potential competing interest was reported by the authors.

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