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Use of tire rubber in mortars as a partial replacement of small aggregates

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A B S T R A C T
Currently, the disposal of rubber tires has generated concern in society due to its irregular dumping. The difficulty in recycling the material and its impact on environment has sparked scientific interest. Researchers are exploring various possible destinations that can be given to this material to prevent environmental impact. Thus, the study investigated the partial replacement of fine aggregates in mortars made for wall coverings with rubber from crushed tires, using the ratios 1:3, 1:5, 1:0.5:3, and 1:1:5, with 5%, 10%, 20%, 40%, and 60% substitution. Laboratory tests were conducted to evaluate the properties of water absorption by capillarity, water absorption by immersion, axial compression strength, and tensile strength by diametric compression. All tests were performed in accordance with the methodologies specified by the respective standards of the Brazilian Association of Technical Standards (ABNT). As a result, it was found that partially replacing 20% of natural fine aggregates (sand) with waste tires did not cause significant compromise in the studied mechanical properties when compared with traditional mortars.

Keywords: Disposal, Coatings, Recycling, Performance.

Uso da Borracha de Pneu em Argamassas como Substituição Parcial dos Agregados Miúdos

R E S U M O
Atualmente, o descarte de pneus de borracha tem gerado preocupação na sociedade devido ao seu descarte irregular. A dificuldade na reciclagem do material e seu impacto ambiental despertaram o interesse científico. Pesquisadores estão explorando diversas destinações possíveis para esse material, visando evitar impactos ambientais. Assim, o estudo investigou a substituição parcial de agregados miúdos por borracha de pneus triturados em argamassas para revestimento de paredes, utilizando os traços 1:3, 1:5, 1:0,5:3 e 1:1:5, com teores de substituição de 5%, 10%, 20%, 40% e 60%. Foram realizados ensaios laboratoriais para avaliar as propriedades de absorção de água por capilaridade, absorção de água por imersão, resistência à compressão axial e resistência à tração por compressão diametral. Todos os ensaios foram conduzidos em conformidade com as metodologias especificadas pelas respectivas normas da Associação Brasileira de Normas Técnicas (ABNT). Como resultado, constatou-se que a substituição parcial de 20% dos agregados miúdos naturais (areia) por resíduos de pneus não comprometeu significativamente as propriedades mecânicas estudadas quando comparadas às argamassas tradicionais.

Palavras-Chaves: Descarte, Revestimentos, Reciclagem, Desempenho.

Uso del Caucho de Neumáticos en Morteros como Sustitución Parcial de los Agregados Finos

R E S U M E N
En la actualidad, la disposición de neumáticos de caucho desechados ha generado una creciente preocupación en la sociedad, ya que, por lo general, se realiza de manera inadecuada. La dificultad para reciclar este material y el impacto que ocasiona al medio ambiente han despertado el interés científico por las diversas posibilidades de aprovechamiento que permitan darle un destino adecuado sin

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causar daños ambientales. En este contexto, el presente estudio evaluó la sustitución parcial de los agregados finos de morteros destinados al revestimiento de paredes por caucho proveniente de la trituración de neumáticos, considerando las dosificaciones 1:3, 1:5, 1:0,5:3 y 1:1:5, con porcentajes de sustitución del 5 %, 10 %, 20 %, 40 % y 60 %. Para ello, se realizaron ensayos de laboratorio con el fin de evaluar las propiedades de absorción de agua por capilaridad, absorción de agua por inmersión, resistencia a la compresión axial y resistencia a la tracción por compresión diametral. Todos los ensayos se llevaron a cabo de acuerdo con las metodologías establecidas en las normas correspondientes de la Asociación Brasileña de Normas Técnicas (ABNT). Al finalizar la investigación, se comprobó que la sustitución parcial del 20 % de los agregados finos naturales (arena) por residuos de neumáticos desechados no produjo un deterioro significativo de las propiedades mecánicas evaluadas, en comparación con los morteros convencionales.

Palabras clave: Desecho, Revestimientos, Reciclaje, Desempeño.

1. Introduction

The current linear economic model promotes excessive consumption of natural resources and generates significant environmental impacts. The major contributor is the high discharge of pollutants at the end of the materials' life cycle (Zhao et al., 2025). For this reason, the transition to a more efficient circular economy model has become a fundamental goal. The primary objective is to reconcile economic growth with sustainable development (Monfared et al., 2025). However, production circularity still accounts for less than 10% of the global economy (Fort and Cerny, 2020).

The construction sector is responsible for approximately 38% of global emissions (Li et al., 2024). Moreover, the construction and demolition waste is the predominant waste stream in the European Union (Zhang et al., 2026). Construction industry produces about 48 million tons of solid waste per year in Brazil alone (ABRELPE, 2022). This scenario highlights the need to seek alternative reuse methods for secondary materials. These methods will enable the transition to a circular economy in construction field.

One of the main challenges faced by modern society is the management of waste tires. The chemical composition of tires hinders their biodegradation. This type of waste can take up to 600 years to decompose. Furthermore, the improper disposal and burning of tires cause negative impacts on the atmosphere, soil, and public health (Anis et al., 2025). In landfills, tires can absorb gases released by the decomposition of other wastes. This phenomenon causes the expansion of tires and, in extreme cases, may lead to explosions that compromise landfill covers. When disposed of in open areas, tires pose risks to public health. The accumulation of rainwater in discarded tires favors the proliferation of disease vectors and contributes to environmental contamination. The burning of tires releases approximately 10 liters of oil per unit, which can infiltrate the soil and reach groundwater, in addition to emitting toxic gases such as carbon, dioxins, polycyclic aromatic hydrocarbons, and other carcinogenic substances (Moreira, Souza and Figueiredo, 2021).

It is estimated that by 2030, approximately 1.2 billion tires will be discarded annually worldwide (Pham et al., 2026). Given this high production volume, tire waste disposal has increased significantly, reinforcing the need for studies focused on recycling and reuse. This highlights the importance of developing simple, energy-efficient, and low-cost methods for recycling tire waste (Sun et al., 2026).

In response, the scientific community and governmental organizations have joined efforts to develop more economical and environmentally friendly methods for recycling rubber waste (Moez et al., 2026). Through reverse logistics, tires can be redirected to production sectors, where they are transformed into products such as mats, rubberized asphalt, synthetic turf, and fuel for the cement industry, among others. In the United States and European Union countries, approximately 80% and 95% of used tires are recycled through different methods, and about 6% to 8% are applied in civil engineering (Laftah et al., 2025; Wang et al., 2020).

Sand is a mineral material formed from the breakdown of various rock types and is widely available in nature. It is an essential raw material for society due to its large-scale use in construction industry, which results in high extraction volumes. According to the Brazilian National Mining Agency (ANM), approximately 312 million tons of sand were extracted in 2017, distributed as follows: 35% for mortars, 20% for concrete production, 15% for construction companies, 10% for precast elements, 10% for retailers, 5% for asphalt paving, and 5% for other uses (ANM, 2019).

Although sand extraction is economically important, it causes numerous environmental impacts, such as water quality degradation, erosion processes, and alterations in river geomorphology.

The use of waste tire rubber as a replacement for fine and coarse aggregates in cementitious matrices presents promising potential for sustainability and material recycling. Several studies have demonstrated the feasibility of incorporating crumb rubber into construction materials (Ahmed et al., 2026; Yuan et al., 2025; Ameri et al., 2021). Ahmed et al. (2026) indicated that the waxy asphalt can be used by adding polymer HDPE in wet process and crumb rubber powder in dry process which significantly increase the Marsall properties and also elevate resistance to moisture damage and permanent deformation. Furthermore, Yuan et al. (2025) revealed that the Crumb rubber modified bitumen (CRMB) showed improvement in performance at high temperature after prolonged thermal exposure, while its resistance to cracking is strongly associated with degree of swelling. Optimizing the processing conditions permitted controlled swelling, resulting in better overall service performance. Similarly, Ameri et al. (2021) highlighted that replacing part of copper slag with crumb rubber in alkali-activated mortars resulted in lower workability and strength but improved thermal insulation, while NaOH treatment enhanced the rubber-binder bond and increase strength. It is recommended to use 10% crumb treated with NaOH for 1 hour to attain best overall performance with environmental benefits.

In addition to the above, Santos et al. (2026) reported that incorporating tire rubber particles into prefabricated gypsum products improves water resistance, reduces density, and enhances thermal and acoustic performance. Wang et al. (2025) highlighted that the usage of waste tire rubber and recycled steel fibers in cement concrete materials can obtain full component utilization of waste tires considering economic and environmental benefit. Similarly, Hassan et al. (2023) observed that replacing 30% of fine aggregates with tire rubber powder enhanced penetration resistance against high-speed projectiles, despite reducing compressive strength.

Singh et al. (2026) found that the compressive strength of concrete produced with 20% tire rubber was reduced by 71.5% that is within the permissible limit for non-structural applications. Miah et al. (2023) verified that the replacement of natural fine aggregate with waste tire fine aggregate does not cause significant effects on the mechanical strength and durability properties of concrete mixtures. The study indicated that the uniaxial compressive strength of concretes containing 20% waste tire fine aggregate reached 20.17 MPa and 18.72 MPa at 28 days for water-to-cement ratios of 0.30 and 0.55, respectively. The authors concluded that the replacement of 20% of natural fine aggregates can be used as a substitute for river sand in many structural concretes whose design strength requirements are not significantly high.

Despite the advances achieved in the incorporation of waste tire rubber into cementitious materials, important knowledge gaps remain regarding the application of this technology in rendering mortars, particularly under conditions representative of the Brazilian context. Most available studies have been conducted in international settings and have focused on structural concrete, whose performance requirements differ from those of rendering mortars. Furthermore, variations in the characteristics of cement, natural aggregates, and tire rubber waste used in different regions may significantly influence material behavior, limiting the direct applicability of findings to national conditions. Although Brazilian studies have investigated the use of tire rubber in cementitious matrices, further research is still needed to comprehensively evaluate its effects on the mechanical, physical, and performance properties of mortars, thereby contributing to the identification of technically feasible and environmentally sustainable replacement levels.

Therefore, this study aims to experimentally evaluate the performance of rendering mortars produced with partial replacement of fine aggregates (sand) by recycled automotive tire rubber. This approach is expected not only to improve mechanical, thermal, and acoustic properties but also to significantly reduce environmental impacts associated with waste generation, promoting circular economy principles and sustainability in the construction industry.

2. Material and Methods

The experimental tests were carried out at the Construction Materials Laboratory of the Centro Universitário Maurício de Nassau (UNINASSAU). Four mortar mix proportions commonly recommended by Brazilian standards for rendering mortars were adopted in this study: i.) 1:3 – W/C = 1.30 (without hydrated lime) – external rendering;ii) 1:5 – W/C = 2.10 (without hydrated lime) – internal rendering;iii) 1:0.5:3 – W/C = 1.30 (with hydrated lime) – external rendering and iv)1:1:5 – W/C = 2.10 (with hydrated lime) – internal rendering.

Hydrated lime (ExtraCal brand), supplied in 20 kg bags, and Portland cement CP II-Z 32 MPa (POTY brand), supplied in 50 kg bags, were used as binders. These brands were selected because they are the most commonly commercialized in construction material stores in Recife, Pernambuco, Brazil.

Fine aggregate consisted of fine sand (GMIX brand) was supplied in 20 kg bags. Prior to use, the sand was oven-dried in a SOLIDSTEEL at a temperature of 100 ± 5 °C for 30 to 40 minutes to eliminate moisture.

In the experimental treatments, a portion of fine sand was replaced by waste tire rubber fine aggregate (WTRFA), composed of rubber residue obtained from shredded automotive tires. The rubber waste was supplied by SK Reciclagem, located in São Sebastião do Passé, Bahia, Brazil. This company performs mechanical shredding of tires and stores the resulting material in 50 kg nylon bags. The WTRFA was sieved through a 2.0 mm mesh to ensure that its particle size distribution was compatible with that of a fine aggregate (Figure 1). No chemical treatment was applied to the rubber particles prior to their incorporation into the mortar mixtures.

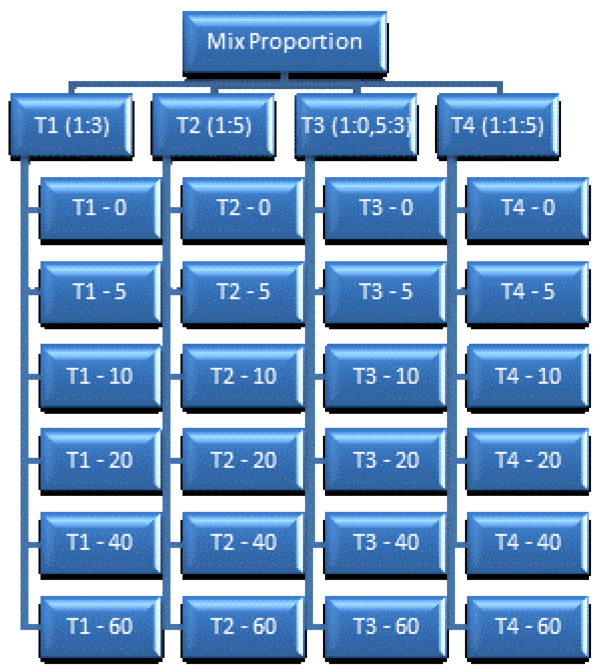
Figure 1 - Sample of rubber used for making mortar
Figura 1 – Amostra de borracha utilizada na fabricação de argamassa

The use of WTRFA without chemical treatment was intended to evaluate its performance under conditions that closely resemble practical applications, allowing the effects of the partial replacement of natural fine aggregate with rubber particles on the properties of the mortar to be assessed independently. Consequently, the results obtained reflect the behavior of the material without surface modification, providing a direct evaluation of the technical feasibility of incorporating WTRFA into rendering mortars.

2.1 Mortar Mixing and Specimen Preparation

For mortar preparation and identification of the test specimens, the percentages of replacement of fine aggregate (sand) by WTRFA were defined, as well as the respective mix proportions. As illustrated in Figure 2, treatments T1, T2, T3, and T4 corresponded to mix proportions 1:3, 1:5, 1:0.5:3, and 1:1:5, respectively.

Figure 2 - Flowchart of the various treatments studied
Figura 2 – Fluxograma dos diversos tratamentos estudados



Each treatment was combined with replacement levels of 0%, 5%, 10%, 20%, 40%, and 60% of sand by WTRFA, identified by the numerical suffix. For example, treatment "T1–0" represents the control mix with no rubber addition, while "T3–20" represents the 1:0.5:3 mix with 20% volumetric replacement of sand by WTRFA.

Mortar mixing followed the procedures established in ABNT NBR 16541 (2016), which specifies the use of a mechanical mixer. Mixing was carried out using an I-3010 electromechanical mortar mixer equipped with two rotational speeds and a 5 L mixing bowl. Initially, the dry constituents were placed in the mixing bowl, and the mixer was operated at low speed. During the first 10 seconds of mixing, 75% of the total mixing water was gradually added, and mixing continued until 30 seconds from the start of operation. Subsequently, the mixer speed was increased and maintained for an additional 60 seconds.

After this stage, the mixer was stopped, and the mortar adhering to the paddle and bowl walls was carefully scraped using a spatula. This scraping process did not exceed 90 seconds; if completed earlier, the mortar was left to rest until the full 90 seconds had elapsed. After the resting period, the final mixing stage was initiated by adding the remaining 25% of the mixing water over 10 seconds, followed by continued mixing for 60 seconds.

Cylindrical test specimens were then molded for each treatment (Figure 3). The specimens were demolded after 72 hours, in accordance with ABNT NBR 13279 (1995), which recommends a demolding period of 48 ± 24 hours.

Figure 3 - Test specimen molding process
Figura 3 – Processo de moldagem de corpos de prova

After curing and demolding, the specimens were subjected to physical, hydraulic, and mechanical characterization tests in accordance with the procedures specified by the corresponding technical standards.

2.2 Apparent Bulk Density (ρ)

The apparent bulk density of hardened mortars was determined by the procedures described in ABNT NBR 13280 (2005), which applies to mortars used for masonry laying and wall and ceiling rendering. Apparent bulk density was calculated using Equation (1):

$$\rho = \frac{m}{v} \qquad (1)$$

where m is the mass of the specimen (g) and v is its volume (cm³). Specimen mass was measured using a BEL precision balance with a maximum capacity of 600 g and a resolution of 0.01 g. The specimen volume was determined using a digital caliper. All specimens were measured and weighed after 28 days of curing.

2.3 Water Absorption by Capillarity

The methodology adopted for the capillary water absorption test was based on ABNT NBR 9779 (2012), with minor adaptations. The test consisted of placing the specimens in a container with a water layer maintained at a constant height of 5 ± 1 mm for all samples (Figure 4).

Figure 4 - Partial View of the Capillary Action Test
Figura 4 – Vista parcial do teste de capilaridade

To ensure full contact between the specimen base and the water layer, the specimens were supported on wooden rods. The test was performed after the specimens had reached 28 days of curing. Before testing, the specimens were abraded with coarse sandpaper and weighed to determine their initial mass. After placement in contact with water, the specimens were weighed again at 10 and 90 minutes. Subsequently, the specimens were split longitudinally to observe the internal capillary rise height (Figure 5).

Figure 5 - Test Specimen after longitudinal rupture
Figura 5 – Corpo de prova após ruptura longitudinal

Capillary water absorption was calculated using Equation (2), in accordance with ABNT NBR 15259:

$$A_t = \frac{m_t - m_0}{S} \quad (2)$$

where A_t is the capillary water absorption (g/cm²), m_t is the specimen mass at time t (g), m_o is the initial mass (g), t corresponds to 10 and 90 minutes, and S is the cross-sectional area of the specimen (cm²).

2.4 Water Absorption by Immersion

Water absorption by immersion was determined in accordance with ABNT NBR 9778 (2005). Three specimens from each treatment were selected after 28 days of curing. The specimens were abraded with coarse sandpaper and cleaned with a brush to remove surface residues. At the next step, they were oven-dried for 72 hours at 105 ± 5 °C and weighed to obtain the dry mass. After drying, the specimens were fully immersed in water for 72 hours. Upon completion of the immersion period, the specimens were removed, surface-dried, and weighed again. Water absorption by immersion was calculated using Equation (3):

$$A = \frac{m_{sat} - m_s}{m_s} . 100 \quad (3)$$

where A is the water absorption by immersion (%), m_{sat} is the saturated mass after immersion (g), and m_s is the oven-dried mass (g).

2.5 Axial Compressive Strength

Axial compressive strength tests were performed in accordance with ABNT NBR 7215 (2019). After mortar preparation, the fresh mixture was immediately placed into cylindrical molds to prevent the onset of setting prior to molding. The mortar was placed in four layers of equal height; each layer compacted with 30 uniform blows using a standard tamping rod.

The molds were stored at ambient temperature for 48 hours to allow initial curing. After this period, specimens were demolded following the procedures specified in the standard to ensure integrity. Afterwards, specimens were cured until the age of 28 days and then tested under compressive loading using a digital manual hydraulic press (20T – NR12, Contenco brand) until failure. Compressive strength was calculated according to ABNT NBR 5739 (2018) using Equation (4):

$$f_c = \frac{4F}{\pi D^2} \quad (4)$$

where fc is the compressive strength (MPa), F is the maximum applied load (N), and D is the specimen diameter (mm).

2.6 Tensile Strength by Diametric Compression

Tensile strength by diametric compression was determined following ABNT NBR 7222 (2011). Specimen molding and curing procedures were identical to those adopted for the axial compressive strength tests. The test consisted of applying a compressive load along the vertical diameter of the cylindrical specimen until failure occurred along the horizontal plane. Tensile strength was calculated using Equation (5):

$$f_{ct,sp} = \frac{2F}{\pi .d.l} \quad (5)$$

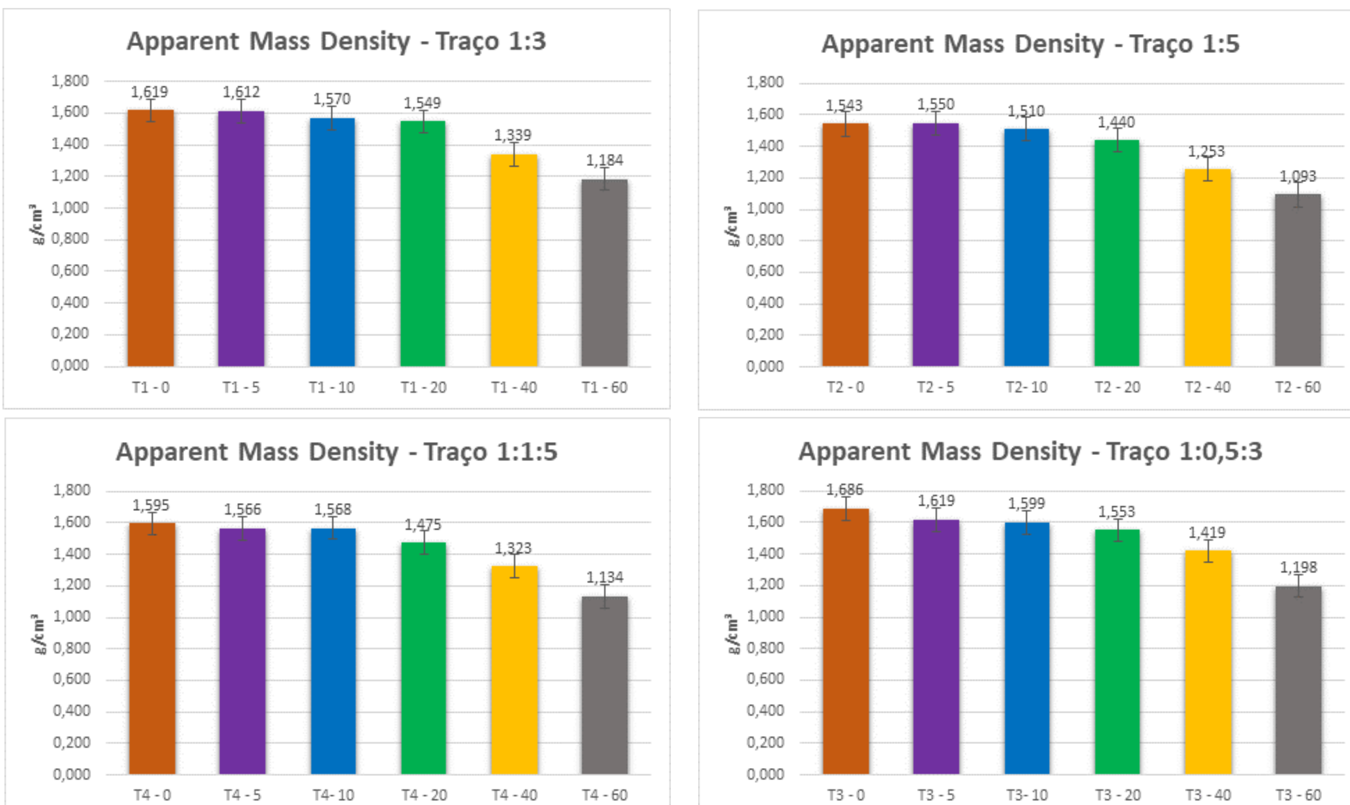
where f{ct,sp} is the tensile strength by diametric compression (MPa), F is the maximum applied load (N), d is the specimen diameter (mm), and l is the specimen length (mm).

3. Results and Discussion

3.1 Apparent Bulk Density

The apparent bulk density values obtained for the different mortar mixes are presented in Figure 6. A clear decreasing trend in apparent bulk density was observed as the percentage of tire rubber incorporated into the mortars increased. The lowest density values recorded for mixtures containing 60% replacement of natural sand by waste tire rubber fine aggregate (WTRFA).

Figure 6 - Apparent Mass Density in the studied traces
Figura 6 – Densidade de massa aparente nos traços estudados

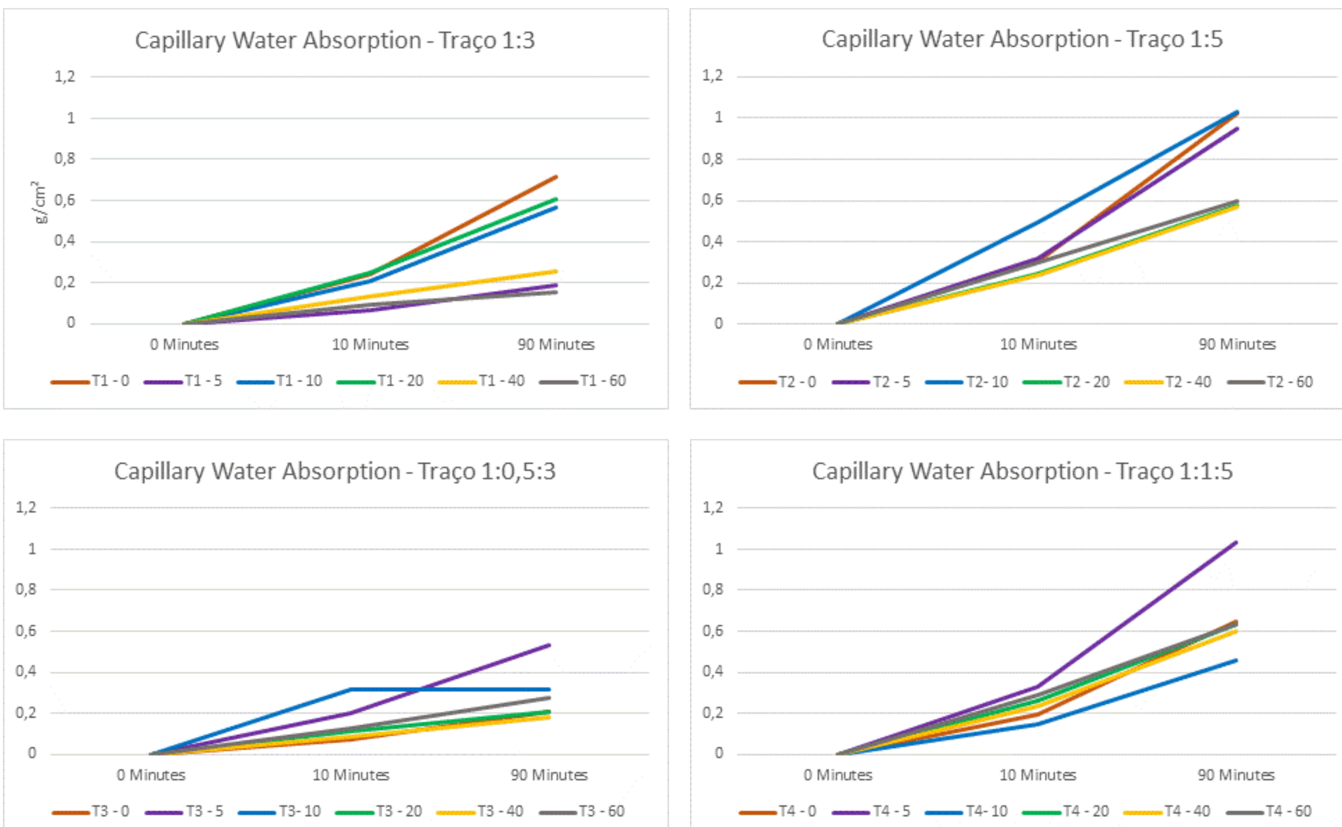


This behavior is primarily associated with the intrinsic density of the materials involved. Preliminary tests indicated that the specific density of natural sand was 2.63 $g \cdot cm^{-3}$, whereas the specific density of tire rubber was 1.17 $g \cdot cm^{-3}$. Therefore, the incorporation of WTRFA, which has a significantly lower density than sand, resulted in lighter mortars. The average reductions in apparent bulk density were approximately 1.56%, 3.00%, 6.60%, 17.24%, and 28.50% for replacement levels of 5%, 10%, 20%, 40%, and 60%, respectively. Similar trends were reported by Miah et al. (2023), who investigated the replacement of natural aggregates with waste tire rubber fine aggregate in concrete and observed reductions in density attributed to the lower weight (69.54% lower than river sand) and lower specific density (66.27% lower than river sand) of rubber particles. The authors also suggested that the incorporation of tire rubber particles may increase void spaces within the cementitious matrix, leading to higher porosity and, consequently, lower bulk density.

3.2 Water Absorption by Capillarity

The results of water absorption by capillarity are shown in Figure 7. The results indicate that, over time, higher capillary water absorption occurred in mortars without the incorporation of WTRFA. In contrast, mortars containing rubber exhibited lower capillary absorption rates.

Figure 7 - Water Absorption by Capillarity
Figura 7 – Absorção de água por capilaridade



In agreement with previous studies (Vidales-Barriguete et al., 2020; Ferrandez et al., 2023), the incorporation of plastic or rubber waste reduces water absorption by capillarity due to the hydrophobic nature of rubber particles. However, in mixes containing hydrated lime, this hydrophobic effect was partially mitigated. For the 1:0.5:3 and 1:1:5 mixes, the highest capillary absorption at 90 minutes was observed at a 5% replacement level of sand by WTRFA.

The addition of hydrated lime to mortar mixtures, in addition to increasing mechanical strength and stiffness in the hardened state, contributes to a reduction in porosity (Santos et al., 2021). Since water is primarily stored within pore structures, changes in pore size distribution and connectivity directly affect capillary absorption behavior. Table 1 presents the classification of the mortars according to the capillary absorption coefficient established by ABNT NBR 13281.

Table 1 – Classification of Mortars according to their Capillary Action (NBR 13281)
Tabela 1 – Classificação de argamassas quanto à capilaridade (NBR 13281)

	Absorption Coefficient g/dm².min$^{1/2}$	**Classification**
T1 – 0	9,40	C5
T1 – 5	2,22	C2
T1 – 10	6,99	C4
T1 – 20	6,88	C4
T1 – 40	2,34	C2
T1 – 60	1,10	C1
T2 – 0	12,81	C6
T2 – 5	12,06	C6
T2 – 10	10,10	C5
T2 – 20	6,25	C4
T2 – 40	6,05	C4
T2 – 60	5,39	C4
T3 – 0	2,59	C3
T3 – 5	6,52	C4
T3 – 10	3,98	C3
T3 – 20	1,85	C2
T3 – 40	1,84	C2
T3 – 60	2,77	C3
T4 – 0	8,87	C5
T4 – 5	13,62	C6
T4 – 10	5,90	C4
T4 – 20	6,97	C4
T4 – 40	6,74	C4
T4 – 60	6,17	C4

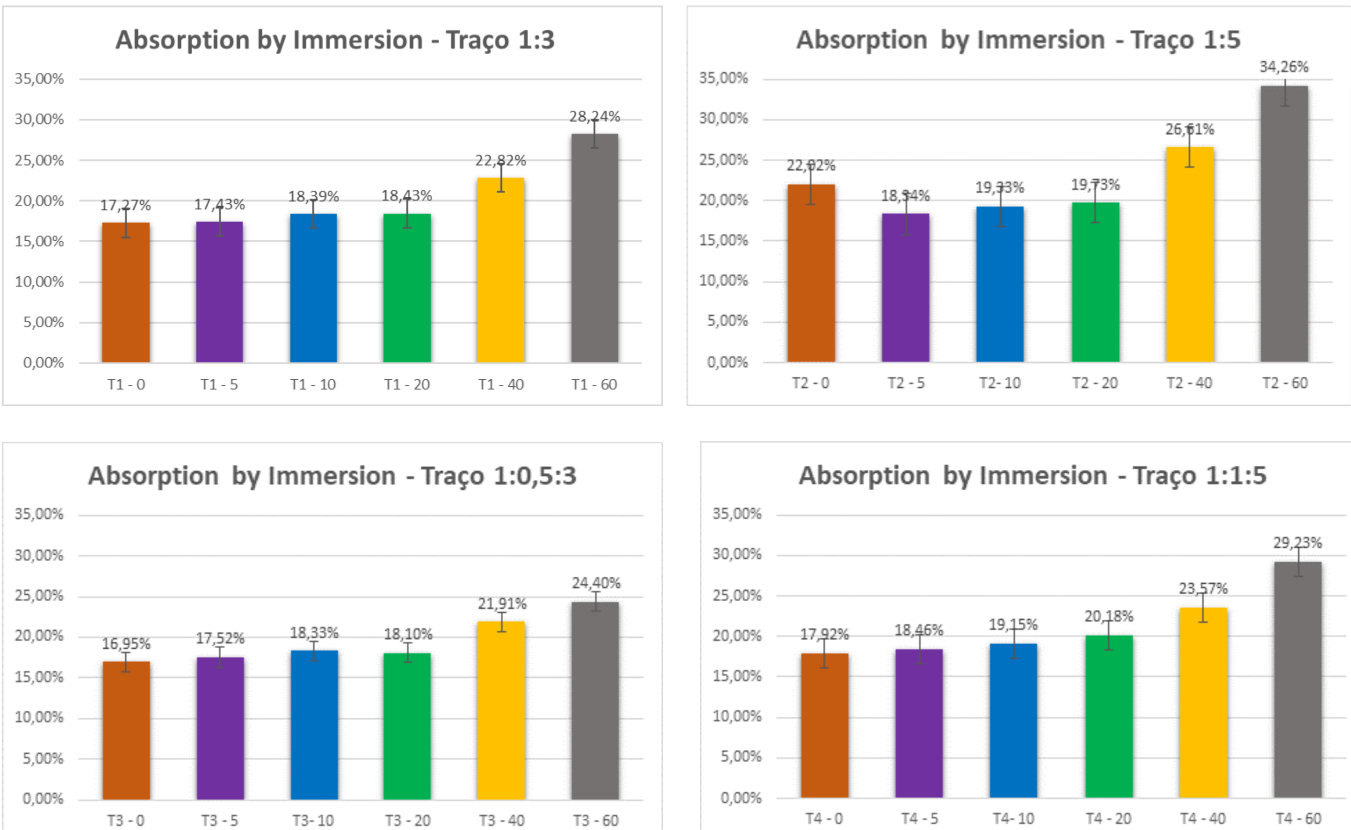
Class C1: Coefficient less than or equal to 1.5 g/dm²·min$^{1/2}$ (lowest water absorption); Class C2: Coefficient from 1.0 to 2.5 g/dm²·min$^{1/2}$; Class C3: Coefficient from 2.0 to 4.0 g/dm²·min$^{1/2}$; Class C4: Coefficient from 3.0 to 7.0 g/dm²·min$^{1/2}$; Class C5: Coefficient from 5.0 to 12.0 g/dm²·min$^{1/2}$; and Class C6: Coefficient greater than or equal to 10.0 g/dm²·min$^{1/2}$ (highest water absorption)

Most industrialized mortars available on the market are classified as C4. Accordingly, the following mixtures met the desirable industry standard: the 1:3 mix with 10% and 20% replacement; the 1:5 mix with 20%, 40%, and 60% replacement; the 1:0.5:3 mix with 5% replacement; and the 1:1:5 mix with 10%, 20%, 40%, and 60% replacement.

3.3 Water Absorption by Immersion

Water absorption by immersion exhibited very similar behavior among the different treatments, as shown in Figure 8. An increase in water absorption was observed only when the replacement level of WTRFA exceeded 40%.

Figure 8 - Water Absorption by Immersion in the Studied Traces
Figura 8 – Absorção de água por Imersão nos Traços Estudados



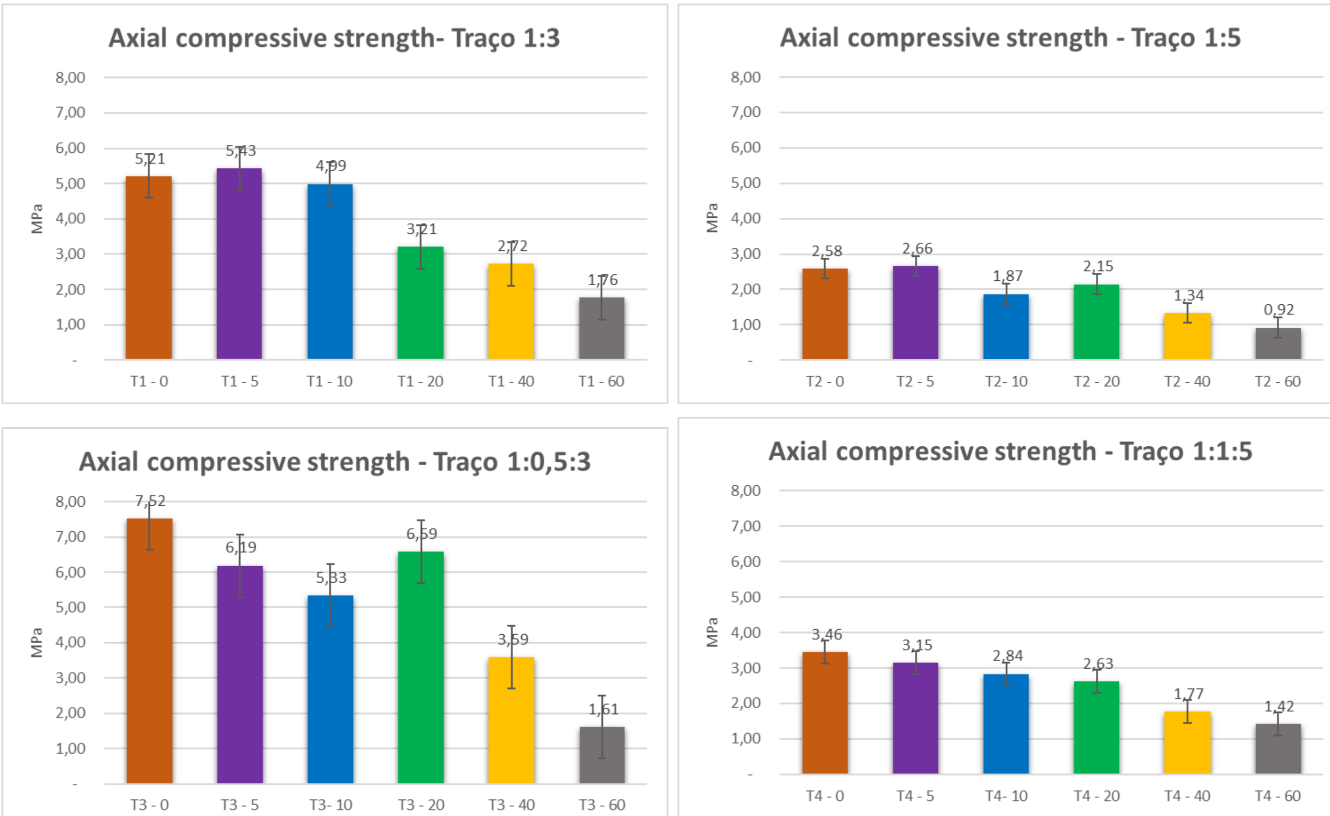
Thakare et al. (2022) also reported increased water absorption with the incorporation of waste tire rubber fibers and attributed this effect to the increased void content in the mortar matrix. The incorporation of WTRFA may increase pore volume and promote pore interconnectivity, facilitating greater water uptake during immersion.

It was also observed that the addition of hydrated lime reduced water absorption, imparting greater impermeability to the mortars. This effect can be attributed to the fine particle size of hydrated lime, which fills voids within the cementitious matrix, thereby reducing overall porosity.

3.4 Axial Compressive Strength

The axial compressive strength results are presented in Figure 9. The results indicate that replacing natural sand with WTRFA tends to lead to a reduction in compressive strength.

Figure 9 - Axial Compressive Strength in the Studied Traces
Figura 9 – Resistência à Compressão Axial nos Traços Estudados



For all mix proportions evaluated, the lowest compressive strength values were observed at the highest replacement level (60%). Compared to the control mortars, the compressive strength of rubberized mortars containing 5%, 10%, 20%, 40%, and 60% WTRFA showed average reductions of approximately 4.8%, 19.7%, 22.9%, 49.2%, and 67%, respectively, at 28 days.

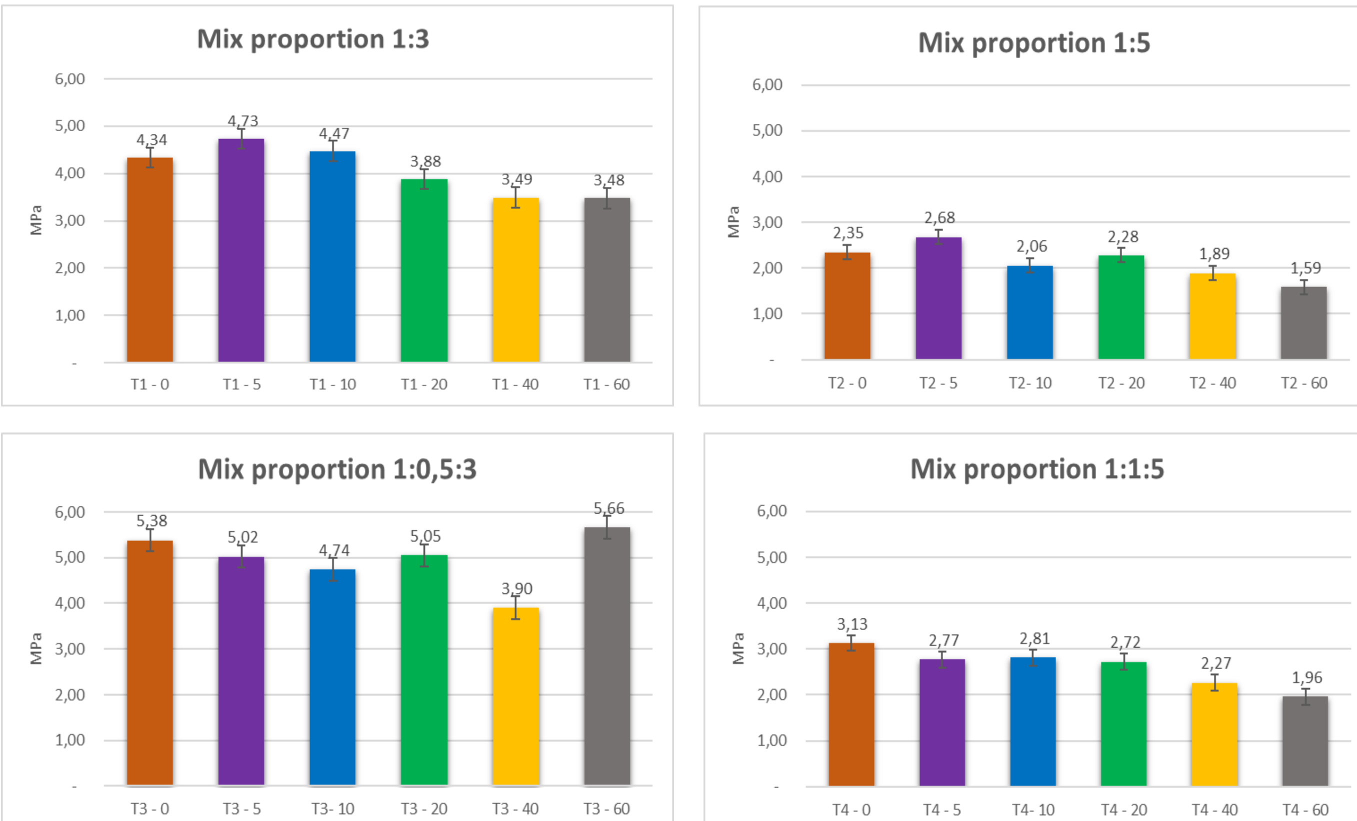
The primary factor contributing to this reduction in compressive strength is the weak interfacial bonding between untreated rubber particles and the cement paste (Miah et al., 2023; Zhu et al., 2023). Despite this general trend, an increase in compressive strength was observed for the 1:3 and 1:5 mixes with 5% WTRFA replacement, which is a desirable outcome, as compressive strength is a key indicator of durability for rendering applications.

Furthermore, for all mix proportions, replacement levels up to 20% resulted in compressive strength values above the minimum recommended limit of 1.5 MPa, indicating technical feasibility for practical applications.

3.5 Tensile Strength by Diametric Compression

The results of tensile strength by diametric compression are shown in Figure 10. This property was only minimally affected by the replacement of sand with WTRFA. The relatively stable tensile strength values suggest that the incorporation of rubber particles did not significantly compromise the material’s resistance to tensile stresses. This behavior may be associated with the energy-absorbing capacity of rubber particles, which can contribute to crack-bridging mechanisms and delay crack propagation under diametric loading.

Figure 10 - Tensile Strength by Diametric Compression
Figura 10 – Resistência à tração por compressão diametral



The results demonstrate that the incorporation of waste tire rubber fine aggregate (WTRFA) significantly alters the physical and mechanical properties of mortars, with the observed effects being directly dependent on the replacement level. Although higher incorporation levels led to a reduction in compressive strength, replacement rates of up to 20% preserved the technical performance required for rendering applications while simultaneously reducing density and improving resistance to capillary water absorption. From an environmental perspective, these findings highlight the potential of recycling waste tires as an alternative to reduce the improper disposal of this environmental liability and decrease the demand for natural aggregates, thereby promoting more sustainable practices and supporting the principles of the circular economy in the construction industry.

4. Conclusion(s)

The large volume of waste tires generated annually. At the same time, the extensive extraction of natural sand required to meet the demands of the construction industry represents a significant global environmental challenge. In this context, this study experimentally evaluated the feasibility of partially replacing natural fine aggregate with waste tire rubber fine aggregate (WTRFA) in rendering mortars. This research also emphasizes the key physical and mechanical properties relevant to coating applications.

The incorporation of WTRFA led to a consistent reduction in the apparent bulk density of the mortars as the replacement level increased. This behavior is directly associated with the lower density of tire rubber compared to natural sand, resulting in lighter mortar composites. Mortars without WTRFA exhibited higher water absorption by capillarity. The addition of rubber particles reduced capillary water absorption due to their hydrophobic nature; however, this effect was partially offset in mixtures containing hydrated lime, which altered the pore structure of the cementitious matrix.

Water absorption by immersion showed similar behavior among most mixtures, with a noticeable increase only at replacement levels above 40%. The presence of hydrated lime contributed to lower water absorption, indicating improved impermeability due to pore filling effects. Axial compressive strength decreased with increasing WTRFA content, primarily due to the weak interfacial bonding between untreated rubber particles and the cement paste. Nevertheless, mortars containing up to 20% replacement of natural sand maintained compressive strength values above the minimum recommended threshold of 1.5 MPa, demonstrating technical viability for rendering applications.

Tensile strength by diametric compression was only slightly influenced by the incorporation of WTRFA, suggesting that the replacement of sand with tire rubber does not significantly compromise tensile performance in rendering mortars. Considering the physical and mechanical performance obtained, the partial replacement of natural sand with WTRFA at replacement levels of up to 20% represents an environmentally promising alternative for rendering mortars. This approach combines technical feasibility with the valorization of solid waste and the reduction in the exploitation of non-renewable natural resources, in accordance with the principles of the circular economy and sustainable construction.

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6. References

Ahmed, A.A.A.A., Morsi, A.G.M. & Eisa, M.S. (2026). Improving the mechanical properties and performance of asphalt mixtures using high density polyethylene and crumb rubber powder. **Case Studies in Construction Materials**, 24(e06011), 1-21. https://doi.org/10.1016/j.cscm.2026.e06011

Ameri, F., Shoaei, P., Musaeei, H.R., Zareei, S.A. & Ban, C.C. (2021). Corrigendum to ‘‘Partial replacement of copper slag with treated crumb rubber aggregates in alkali-activated slag mortar. **Construction and Building Materials**, 283 (123212). https://doi.org/10.1016/j.conbuildmat.2021.123212

ABRELPE - Associação Brasileira de Empresas de Limpeza Pública e Resíduos Especiais (2022). **Panorama dos Resíduos Sólidos no Brasil**. 64p.

Anis, S., Sukarni, S., Azeez, A., Siswantara, A.I., Maulana, S., Fitriyana, D.F., Kusumastuti, A., Siregar, J.P., Palanisamy, S., Alagarsamy, A., Abbas, M., Kalathil, S. & Belay, M. (2025). Thermogravimetric and physicochemical characterization of waste tire–coconut shell blends as potential renewable energy feedstock, **Journal of Royal Society of Chemistry**, 4(1), 537-550. https://doi.org/10.1039/d5su00712g

ANM - Agência Nacional de Mineração (2019). **Sumário Mineral 2017**. Brasília-DF, 201p.

Brasil. Associação Brasileira de Normas Técnicas – ABNT (1995). **NBR 13529: Revestimentos de paredes e tetos de argamassas inorgânicas**. Rio de Janeiro, 8p.

Brasil. Associação Brasileira de Normas Técnicas – ABNT (2005). **NBR 9778: Argamassa e Concreto Endurecidos - Determinação da Absorção de Água por Imersão - Índice de Vazios e Massa Especifica**. Rio de Janeiro, 4p.

Brasil. Associação Brasileira de Normas Técnicas – ABNT (2005). **NBR 13280: Argamassa para assentamento e revestimento de paredes e tetos – determinação da densidade de massa aparente no estado endurecido**. Rio de Janeiro, 2p.

Brasil. Associação Brasileira de Normas Técnicas – ABNT (2011). **NBR 7220: Concreto e argamassa – determinação da resistência à tração por compressão diametral de corpos de prova cilíndricos**. Rio de Janeiro, 5p.

Brasil. Associação Brasileira de Normas Técnicas – ABNT (2012). **NBR 9779: Argamassa e concreto endurecidos absorção de água por capilaridade**. Rio de Janeiro, 3p.

Brasil. Associação Brasileira de Normas Técnicas – ABNT (2016). **NBR 16541: Argamassa para assentamento e revestimento de paredes e tetos – preparo da mistura para a realização de ensaios**. Rio de Janeiro, 6p.

Brasil. Associação Brasileira de Normas Técnicas – ABNT (2018). **NBR 5739: Concreto – Ensaio de compressão de corpos de prova cilíndricos**. Rio de Janeiro, 9p.

Brasil. Associação Brasileira de Normas Técnicas – ABNT (2019). **NBR 7215: Cimento Portland – Determinação da resistência à compressão de corpos de prova cilíndricos**. Rio de Janeiro, 12p.

Ferrandez, D., Yedra, E., Recalde-Esnoz, I. & del Castillo, H. (2023). Reuse of end-of-life tires and their impact on the setting time of mortars: Experimental study using a new measuring equipment. **Journal of Building Engineering**, 69(106255), 1-17. https://doi.org/10.1016/j.jobe.2023.106255

Fort, J. & Cerny, R. (2020). Transition to circular economy in the construction industry: Environmental aspects of waste brick recycling scenarios. **Waste Management**, 118, 510-520. https://doi.org/10.1016/j.wasman.2020.09.004

Hassan, Z., Sakai, Y. & Watanabe, K. (2023). Penetration resistance and damage characteristics of cementitious mortar with partially replaced waste tire rubber as a filler against high-speed impact loading. **Journal of Building Engineering**, 80(108039), 1-26. https://doi.org/10.1016/j.jobe.2023.108039

Li, K., Zou, Z., Zhang, Y. & Shuai, C. (2024). Assessing the spatial-temporal environmental efficiency of global construction sector. **Journal of Science of the Total Environment**, 951(175604). https://doi.org/10.1016/j.scitotenv.2024.175604

Laftah, W.A. & Rahman, W.A.W.A. (2025). A comprehensive review of tire recycling technologies and applications. **Royal Society of Chemistry**, 6 (15), 4992-5010. https://doi.org/10.1039/d5ma00463b

Miah, M.J., Huaping, R., Paul, S.C., Babafemi, A.J., Sharma, R. & Jang, J.G. (2023). Performance of eco-friendly concrete made from recycled waste tire fine aggregate as a replacement for river sand. **Structures**, 58(105463). https://doi.org/10.1016/j.istruc.2023.105463

Moreira, A.R., Gonçalves, H.M. de S. & Figueiredo, A.P. de (2021). Reciclagem de pneus inservíveis para cobertura diária alternativa de aterro sanitário de pequeno e médio porte. **Revista Verde de Agroecologia e Desenvolvimento Sustentável**, 16(3), 332-337. https://doi.org/10.18378/rvads.v16i3.9188

Moez, A. & Fattahi, S.M. (2026). Upcycled engineered earth from recycled sand via hybrid carbonate – hydroxide activation of slag with waste brick powder and recycled rubber fibers. **Journal of Materials and Design**, 266(116187), 1-21. https://doi.org/10.1016/j.matdes.2026.116187

Monfared, M., Marandi, F. & Sauer, P. (2025). Achieving sustainable development by integrating circular economy principles into solid waste management: A systematic literature review and research agenda, **International Journal of Production Economics**, 290(109787), 1-20. https://doi.org/10.1016/j.ijpe.2025.109787

Pham, T.T., Ngo, S.H., Trinh, T.H. & Pham, T.H. (2026). Impact resistance and low-carbon potential of concrete using rubber from scrap tires. **Journal of Next Materials**, 12(102366), 1-12. https://doi.org/10.1016/j.nxmate.2026.102366

Santos, P., Alvoeiro, F., Ferrandez, D., Benzal, A.Z., Sanchez, E.A. & Duraes, L. (2026). Innovative gypsum composites and silica aerogels based on recycled tyre rubber colloidal solution for high thermal performance LSF systems. **Applied Materials Today**, 51(103344), 1-23. https://doi.org/10.1016/j.apmt.2026.103344

Singh, S., Zeng, H. & Kim, H.J. (2026). Performance evaluation of concrete pavement incorporating recycled rubber tire mulch for urban heat island mitigation. **Journal of Next Sustainability**, 7(100303). https://doi.org /10.1016/j.nxsust.2026.100303

Sun, Q., Zhai, Y., Li, Z., Ye, X., Zhang, L. & Wang, Y. (2026). Efficient electromagnetic wave absorption of porous 3D heterogeneous composites based on Fe3O4 / waste–tyre–recycled carbon black (RCB) hybrids. **Journal of Composites Communications**, 62(102728). https://doi.org /10.1016/j.coco.2026.102728

Santos, A. M., Costa e Silva, A. J. & Mota, J.M.F. (2021). Influência da Adição de Cal Hidratada na Aderência do Preparo da Base Chapisco e Argamassa para Revestimento. **Revista Matéria**, 24(3), 1-15. https://doi.org/10.1590/S1517-707620210003.13039

Thakare, A.A., Gupta, T., Deewan, R. & Chaudhary, S. (2022). Micro and macro-structural properties of waste tyre rubber fibre-reinforced bacterial self-healing mortar. **Construction and Building Materials**, 322(126459). https://doi.org/10.1016/j.conbuildmat.2022.126459

Vidales-Barriguete, A., Atanes-Sanchez, E., Rio-Merino, M. & Pina-Ramirez, C. (2020). Analysis of the improved water-resistant properties of plaster compounds with the addition of plastic waste. **Construction and Building Materials**, 230(116956). https://doi.org/10.1016/j.conbuildmat.2019.

Wang, J., Zhao, C., Li, Q., Song, G. & Hu, Y. (2025). The synergistic effect of recycled steel fibers and rubber aggregates from waste tires on the basic properties, drying shrinkage, and pore structures of cement concrete. **Journal of Construction and Building Materials**, 470(140574). https://doi.org/10.1016/j.conbuildmat.2025.140574

Wang, Q.Z., Wang, N.N. & Tseng, M.L. (2020). Waste tire recycling assessment: road application potential and carbon emissions reduction analysis of crumb rubber modified asphalt in China, **Journal of Cleaner Production**, 249(4):119411. https:// 10.1016/j.jclepro.2019.119411.

Yuan, J.; Jin, T., Cheng, H., Li, M., Wang, Z. & Sun, L. (2025). Performance evolution and technique optimization of crumb rubber modified bitumen under thermal effect throughout the production and construction process. **Fuel**, 394(135115). https://doi.org/10.1016/j.fuel.2025.135115

Zhang, C., Hu, M., Pohjalainen, E., Maio, F.D. & Stegemann, J.A. (2026). Enhancing the uptake of secondary raw materials in the construction sector through reuse and recycling. **Chem Circularity**, 1(100013), 1-17. https://doi.org/10.1016/j.checir.2026.100013

Zhao, G., Pan, X., Yan, H., Tian, J., Han, Y., Guan, H., Ruan,Y., Liu, B. & Chen, F. (2025). Recycling shield discharged soil to produce sustainable controlled low-strength material: Performance, microscale characterisitics, and environmental life cycle assessment. **Journal of Sustainable Materials and Technologies**, 46(e01717). https://doi.org/10.1016/j.susmat.2025.e01717

Zhu, Z., Lu, Y. & Zhou, M. (2023). A functionalized waste tire rubber powders for mitigating leaching of heavy metal ions and enhancing photocatalytic properties of rubberized cement mortar. **Journal of Building Engineering**, 78(107749). https://doi.org/10.1016/j.jobe.2023.107749