

Physico – mechanical properties of masonry bricks with recycled tire rubber: an approach to sustainability and waste valorisation

Propiedades físico – mecánicas de ladrillos para mampostería con caucho reciclado de neumáticos: un enfoque en la sostenibilidad y la valorización de residuos

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ABSTRACT

The improper management of end-of-life tyres (ELTs) poses an environmental and public health challenge due to their prolonged biodegradation. In response to this problem, the influence of the incorporation of recycled rubber (RC) on the physical and mechanical properties of clay bricks was determined, with the purpose of knowing its potential as a sustainable construction material. The research was applied, employing an experimental design, a quantitative approach, and an explanatory level. The experimental process consisted of manufacturing 100 bricks with different proportions (5%, 10% and 15%) of CR and evaluating the effect on their properties through laboratory tests. The results showed a significant influence of the three proportions of CR on the physical and mechanical properties of the bricks, specifically in the dimensional variation (width and height), concave warping, water absorption, suction and compressive strength, with a *p-value* < 0.05 in all cases. The results support the conclusion that the incorporation of CR (5%, 10% and 15%) influences the properties of clay bricks and their use for masonry is viable, as they comply with the standards established by the current Peruvian regulations (Standard E.070. Albañilería [Masonry]).

Keywords: Wastes; bricks; building materials; waste treatment; materials engineering.

1. INTRODUCTION

The exponential generation of solid waste and the inefficiency in its final disposal constitute one of the greatest environmental challenges on a global scale. Population growth and the rising demand for resources inevitably lead to this accumulation of waste, the volume of which is projected to increase by approximately 66% between 2023 and 2050 (United Nations Environment Programme, 2024). Within this context, vehicular transport has become a fundamental component of socio-economic development (Alarcón et al., 2020; World Bank, 2024), directly impacting the production and consumption of tyres (Deng et al., 2023; Zerin et al., 2023). Consequently, End-of-Life Tyres (ELTs) represent a critical, voluminous, and difficult-to-manage waste stream. In fact, it is estimated that only 10% of tyres worldwide are recycled (Ferdous et al., 2021), an alarming figure considering their slow biodegradation.

Under this scenario, these residues are referred to as 'black pollution', as their traditional management is detrimental to the environment and public health (Anisa et al., 2023; Hu et al., 2024; Zhao et al., 2024). Consequently, there is a compelling need to develop valorisation solutions, the success of which is intrinsically linked to the environmental regulations and development policies of each country. In jurisdictions with advanced regulatory frameworks, such as the nations comprising the European Union, the recovery rate of ELTs is significant and shows a growing trend. Indeed, in 2018, 94% of this waste was successfully processed (Grammelis et al., 2020), the most recent data indicate that this figure has risen to 97% (Tyres Europe, 2021). However, there is a marked contrast with the Latin American region, where the deficient development of ELT management and recycling programmes results in a large portion not being recovered and ending up in informal landfills, a practice that persists despite being prohibited in many of the jurisdictions (Martínez, 2021; Ferronato et al., 2023).



In Peru, the management of ELTs constitutes a particular environmental challenge. Despite their recognised negative impact on the environment and health, current legislation does not consider the ELT as a hazardous waste in itself; hazardousness would only apply if it were mixed with any other waste deemed hazardous (Decreto Supremo N°014-2017-MINAM, 2017). However, it was not until 2021 that a special regime was approved for the management of ELTs. This framework is focused on guaranteeing the appropriate and environmentally sound handling of this waste, from collection to valorisation, while also establishing clear responsibilities for producers, marketers, municipalities, and waste operators (Decreto Supremo N°024-2021-MINAM, 2021).

The valorisation of ELTs is oriented towards material and energy recovery for various industries, highlighting the growing scientific interest in the potential of recycled rubber as a sustainable input in the construction sector. Several authors have demonstrated that the incorporation of rubber into bricks complies with standard strength requirements, while also improving thermal and acoustic performance (Erdoğan et al., 2023; Gambin et al., 2023; Wang y Du, 2020). This improvement in insulating properties is complemented by a reduction in the unit weight of constructive elements and lower production costs (Abubakar et al., 2022; Damiani et al., 2021). However, investigations such as those by Al-Fakih et al. (2020) warn that these properties remain within acceptable ranges provided that the dosage does not exceed 20% – 30%.

At a national level, there are also some experiences regarding the use of recycled rubber (RR) in masonry materials. Studies confirm that, although RR tends to decrease the compressive strength of the bricks, the tested dosages (ranging from 4% to 30%) often comply with the minimum requirements established by Peruvian regulations (Cabrera y Cercedo, 2021; Caceres y Mamani, 2021; Lizarzaburu et al., 2023; Soncco, 2024).

The reuse of solid waste is a crucial axis for sustainability, driven by a paradigm shift towards a circular economy. This proposal seeks to ensure that materials circulate in closed-loop systems, in order to maintain their value and minimise waste generation and resource exploitation in construction (Benachio et al., 2020; Hossain et al., 2020). Although various studies have evaluated the use of RR in construction materials, the literature specifically focused on clay bricks remains limited. Therefore, it is necessary to address this gap to clarify discrepancies in previous results and provide robust data within specific regulatory contexts.

Within this context, the main purpose of this study is to evaluate the effect of RR on the production of clay bricks intended for masonry. This effect is assessed through its impact on the physical and mechanical properties of the units. Furthermore, the study seeks to determine the economic and environmental viability of valorising this waste within the construction industry.

2. METHODOLOGY

2.1 Sample preparation

The study focused on analysing four groups of bricks classified according to the proportion of recycled rubber incorporated in their manufacture: 0%, 5%, 10%, and 15% (Table 1). To obtain the recycled rubber particles, a preliminary collection process of end-of-life tyres (ELTs) was conducted, sourcing from both landfills and collection centres. These tyres were cleaned to remove metallic components, then mechanically shredded and incorporated into the clay mixture for brick production (Figure 1).

A total of 100 clay bricks were manufactured, consisting of 25 units per group. Subsequently, 10 units were randomly selected from each group for quality control testing, resulting in a total of 40 bricks for testing. This sample size per group was adopted based on the sampling recommendations established in Standard E. 070 Albañilería [Masonry] (applicable to batches of up to 50,000 units).

Table 1. Characterization of the bricks from the four study groups

Brick group	Total weight (g)	Recycled Rubber (%)	Clay (%)	Sand (%)	Water (%)	Wet unit dimensions (cm)
Group 1	4300	0%	56.05%	25.35%	18.60%	Length: 21 cm Width: 12.40 cm Height: 8 cm
Group 2	4260	5%	53.29%	23.87%	17.84%	
Group 3	4220	10%	50.00%	22.94%	17.06%	
Group 4	4180	15%	47.37%	21.36%	16.27%	

Nota: The recycled rubber used consisted of particles passing through a No. 30 sieve (0.60 mm), in accordance with sieve analysis.



Figure 1. Production of eco-friendly clay bricks: A) Collection of ELTs, B) Shredded recycled rubber from ELTs, C) Clay bricks with incorporated rubber.

2.2 Data collection

The bricks were subjected to five laboratory tests to determine their physical and mechanical properties: dimensional variation, warpage, water absorption, compressive strength, and suction. These tests and their respective requirements are stipulated by the Reglamento Nacional de Edificaciones (RNE - National Building Regulations), specifically through the Standard E.070. Albañilería [Masonry]. The results of these tests were recorded on laboratory data sheets.

2.3 Data Analysis

To assess the influence of recycled rubber content on the bricks, the results were compared with the requirements established in the Peruvian regulatory framework for these construction units. Additionally, a one-way ANOVA was performed to evaluate differences between groups.

3. RESULTS AND DISCUSSION

3.1 Physical and mechanical properties of the bricks

The results of the physical and mechanical properties for the four study groups, obtained from the laboratory tests, are presented in Table 2.

Table 1. Physical and mechanical properties of bricks

Brick property	Group 1 (RR=0%)	Group 2 (RR=5%)	Group 3 (RR=10%)	Group 4 (RR=15%)	Standard E. 070 (Type I brick)
Dimensional variation	L: 0.36% W: 0.31% H: 0.27%	L: 0.58% W: 0.65% H: 1.01%	L: 0.94% W: 1.38% H: 1.41%	L: 0.98% W: 1.95% H: 1.29%	L: $\pm 4\%$ W: $\pm 6\%$ H: $\pm 8\%$
Warpage	Max.: 1.80 mm Min.: 0.45 mm	Max.: 1.46 mm Min.: 0.54 mm	Max.: 1.61 mm Min.: 0.57 mm	Max.: 1.84 mm Min.: 0.56 mm	≤ 10 mm
Water absorption	Avg.: 20.09%	Avg.: 18.08%	Avg.: 16.98%	Avg.: 17.95%	$\leq 22\%$
Suction	Avg.: 18.55 g	Avg.: 16.67 g	Avg.: 15.64 g	Avg.: 14.84 g	10 to 20 g/200 cm ² ·min
Compressive strength (28 days)	Avg.: 49.54 kg/cm ²	Avg.: 53.66 kg/cm ²	Avg.: 55.97 kg/cm ²	Avg.: 58.16 kg/cm ²	≥ 50 kg/cm ²

Nota: L: length, W: width, H: height, Max.: maximum, Min.: minimum, Avg.: average

The obtained physical and mechanical property values comply with the requirements for a Type I brick unit, as established in Standard E.070.

Regarding dimensional variation, the results obtained for all specimens (maximum 1.95%) are significantly below the maximum limits permitted by regulations for units of this class. These results are consistent with previous studies, such as Weepiu (2020) and Palomino et al. (2025), who reported variations of less than 1% with the incorporation of RR. Likewise, the values are consistent with the findings of Lizarzaburu et al. (2023), who, when manufacturing units with rubber and PET under the Standard E.070, obtained variations of a mere

0.29% in length and 0.84% in width in their prototypes. Consequently, the results and previous literature confirm that the controlled incorporation of RR maintains dimensional stability within the tolerances established by Standard E.070. These low percentages ensure that the incorporation of RR does not compromise the modular coordination nor the proper execution of bond patterns in masonry walls.

Regarding warpage, all specimens exhibited deformations of less than 1.84 mm well below the 10 mm limit established for Type I bricks. Another author, Farfan (2019), in his research on bricks incorporating a mixture of polyethylene terephthalate and higher proportions of RR (6%, 12%, and 18%), found warpage values of 2.13 mm and 2.08 mm, which are also below the maximum established in the Peruvian standard. Compliance with this parameter is fundamental to ensuring the flatness of the load-bearing faces. This demonstrates that the incorporation of RR at the evaluated concentrations preserves both the dimensional stability and the geometric integrity of the units, without compromising their constructive quality.

The average water absorption values obtained from laboratory testing (maximum 20.09%) did not exceed the 22% cap established for clay masonry units in the Standard E.070. This result is similar to those reported by Weepiu (2020), who also found absorption levels below 22% for bricks with similar RR dosages. Furthermore, these findings are consistent with Atencio (2025), who, in her study on ecological bricks incorporating NFU and PET, recorded absorption values ranging from 9.95% to 11.15%. In this sense, the results confirm that the incorporation of RR does not compromise the relative impermeability or porosity of the units, which is essential for mitigating volumetric variations and premature degradation. Consequently, adequate behaviour towards moisture is achieved, allowing the bricks to maintain their physical integrity, durability, and stability under prolonged exposure to environmental humidity.

The suction values ranged between 14.84 y 18.55 (g/200 cm²·min), placing them well within the recommended range established by Standard E.070. The results differ from those found by Weepiu (2020), as for proportions equal to those of this study, they found suctions greater than 20 g/200 cm²·min. Consequently, the evidence confirms that the RR dosage maintains the suction of the unit at optimal levels, guaranteeing adequate bond strength with the mortar without the need for pre-saturating the bricks. This ensures the integrity of the joints and the overall constructive quality of the masonry wall.

Finally, compressive strength (f'b) analyses showed average values ranging from 49.54 kg/cm² to 58.16 kg/cm², with most units reaching or exceeding the 50 kg/cm² threshold, thereby allowing their classification as Type I bricks in accordance with Standard E.070. These results are higher than those reported by Gambin et al. (2023), who obtained a compressive strength of 2.89 MPa (≈29.5 kg/cm²) for bricks incorporating 7% recycled rubber, a value which nevertheless exceeds the minimum requirement of 2 MPa established by Colombian regulations. Similarly, at the national level, Cabrera and Cercedo (2021) reported strengths exceeding 70 kg/cm² in units containing up to 12% recycled rubber, meeting the requirements set out in Standard E.070. Taken together, the evidence suggests that the incorporation of recycled rubber does not compromise the integrity of the clay matrix, maintaining strength above the regulatory threshold. This ensures the mechanical capacity required to withstand design loads, supporting the viability of recycled rubber as a material that contributes to the load-bearing capacity and structural safety of the units.

3.2 Influence of Recycled Rubber on the production of masonry bricks

A one-way ANOVA (Table 3) was conducted to analyse the influence of RR on brick production, specifically its effects on physical and mechanical properties.

Table 2. Influence of Recycled Rubber (RR) on brick properties (ANOVA Analysis)

Brick property	Description	Significance (p-value)
Dimensional variation	Length variation	0.512
	Width variation	0.000
	Height variation	0.000
Warpage	Convex	0.123
	Concave	0.014
Water absorption	Water absorption	0.004
Suction	Suction	0.000
Compressive Strength	Compressive strength (28 days)	0.000

Statistical analysis reveals no significant differences in length variation ($p\text{-value} = 0.512$) or convex warping ($p\text{-value} = 0.123$), as both are greater than the established significance level ($\alpha = 0.05$). The absence of critical variability in these dimensions is favourable, as it prevents deficiencies during the laying process and precludes the reduction of the structure's mechanical strength caused by geometric irregularities. Conversely, significant differences ($p\text{-value} < 0.05$) were identified in width, height, concave warping, water absorption, suction, and compressive strength. These findings are consistent with the ANOVA results reported by Olofinnade and Adeyinka (2024), who demonstrated that while certain physical dimensions can remain stable, the dosage of recycled rubber has a statistically significant effect ($p\text{-value} < 0.0001$) on the compressive strength and water absorption of the units. Similarly, Cabrera and Cercedo (2021) determined that RR significantly influences these same properties ($p\text{-value} = 0.000$). Consequently, the incorporation of rubber positively influences compressive strength, absorption, and suction, which are properties closely linked to the modification of the ceramic microstructure. The interaction between RR and clay optimises the internal matrix, enabling the production of units with lower unit weight and enhanced bond strength. Furthermore, this synergy improves thermal and acoustic insulation without detrimental effects on structural integrity.

3.3 Economic analysis of the production of bricks with Recycled Rubber

An economic analysis of the brick manufacturing process was conducted, evaluating cost variations relative to incremental increases in recycled rubber content. Group 1, consisting of bricks without rubber, served as the control group.

Table 4. Economic analysis of manufacturing bricks with recycled rubber (RR)

Brick group	Recycled Rubber content (kg)	Total unit cost (S/.)	Cost difference (S/.)
Group 1 (RR=0%)	0.000	0.907	-
Group 2 (RR=5%)	0.213	0.954	+0.047
Group 3 (RR=10%)	0.422	1.003	+0.096
Group 4 (RR=15%)	0.627	1.048	+0.141

Table 4 shows that the costs for groups 2, 3, and 4 are higher than those of the control group, with increments of S/. 0.047, S/. 0.096, and S/. 0.141, respectively. Consequently, the incorporation of RR increases the production cost of these units. This result aligns with previous literature, such as that by Peña (2019), who also reported higher costs for bricks incorporating RR, reaching an increase of up to S/. 0.21 soles. Although an economic increase in production is verified, it is crucial to weigh this cost against the environmental and social benefits derived from the use of components sourced from industrial waste.

4. CONCLUSIONS

This research confirms that the incorporation of End-of-Life Tyre (ELT) recycled rubber into the production of eco-friendly clay bricks functions as an effective modifier, significantly influencing key physical-mechanical properties. ANOVA statistical analysis demonstrates that RR dosages exert a substantial impact on width and height variation, concave warpage, water absorption, compressive strength, and suction. Notably, formulations containing up to 15% RR successfully comply with the requirements established by Standard E.070 for a Type I brick. However, the inclusion of RR results in a marginal increase in the unit cost of the bricks. Therefore, it is strategically recommended to conduct a comprehensive cost-benefit analysis to identify the optimal RR percentage that balances enhanced critical properties, such as compressive strength, against a commercially viable cost threshold.

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