Research paper

Recycled Plastic Waste as Aggregates in Lightweight Concrete: A Study of Saturation Effects

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Abstract

The construction industry plays a significant role in the depletion of natural resources and the emission of atmospheric pollutants. As a sustainable alternative, this study investigates the reuse of polypropylene plastic waste as a partial replacement for natural coarse aggregate in lightweight concrete. The main objective was to evaluate the effects of replacing 30% of conventional crushed aggregate (coarse aggregate) with plastic waste under four pre-treatment conditions: Dry, saturated with water, saturated with cement and saturated with silica fume. Experimental tests assessed both fresh (workability and specific weight) and hardened (compressive strength, porosity, water absorption, and void ratio) properties of concrete. The results indicated that the lamellar shape and smooth surface of the plastic waste hindered its interaction with the hardened cement paste matrix, resulting in increased porosity, higher water absorption, and reduced compressive strength across all treatments. Contrary to the initial hypothesis, pre-saturation of the plastic waste did not improve the interfacial transition zone; instead, it further compromised bonding and mechanical performance. Nevertheless, the dry plastic waste mixture presented satisfactory compressive strength for lightweight concrete applications, i.e. compressive strength > 10 MPa. Overall, the use of polypropylene plastic waste contributes to reducing environmental impacts and promotes the production of low-density concrete for non-structural applications.

Keywords: Recycled Aggregate · Polypropylene Plastic Waste Aggregates · Lightweight Concrete · Compressive Strength · Water Absorption

1. INTRODUCTION

The construction industry plays an essential role in a country's economic development. It stimulates an extensive production chain, rapidly drives economic growth, and is responsible for a significant portion of GDP (Gross Domestic Product)(Chiang et al., 2015; Qabaja and Tenekeci, 2024). However, the unbridled growth of this industry generates major environmental impacts, requiring urgent attention and measures to ensure sustainability (Chen et al., 2023). In terms of construction materials, concrete is widely used throughout the world. Considering all consumable materials, it is ranked second after water. Therefore, it is essential that concrete production activity should be reconciled with sustainable growth, adopting practices that are less harmful to the environment (Santhosh et al., 2021; Shen et al., 2022).

To meet society's demands and comply with legal requirements, the construction industry has intensified its efforts to reduce waste and adopt more sustainable practices. Increasingly strict environmental legislation encourages companies to carry out material disposal studies and implement measures to minimise the environmental impacts of their activities. This context promotes the use of different types of waste as aggregates for concrete. Examples include the use of glass aggregates, sawdust aggregates, PVC (Polyvinyl chloride) aggregates, and waste tile aggregates in concrete and mortar, seeking sustainability in the production of

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cementitious materials (Ehsan Farahinia et al., 2024; Mahdi Amirnia et al., 2024; Pournoori et al., 2024). Another waste that appears prominently in research on sustainability in construction materials is plastic waste.

According to dedicated research (Tudu et al., 2024), population growth and the urbanisation process have contributed significantly to the increase in the consumption of plastic products and, consequently, to the exacerbated generation of this waste. However, only a small part of this material is recycled properly, resulting in significant adverse impacts on ecology and the environment due to the accumulation of non-recycled plastic waste. Among the various types of plastics, polypropylene stands out, which, according to (Rosato, 2020), is the second most produced plastic in volume, after polyethylene. Global polypropylene production was 56 MMT (million metric tons) in 2018 and is estimated to reach 83 MMT by 2025, at an annual growth rate of 5.85%.

Research states that virgin polypropylene is one of the most widely used plastics globally, due to its versatility, low cost and high mechanical strength (Nguyen and Edalati, 2024; Yan et al., 2023). The versatility of polypropylene is due to its unique molecular arrangement, composed of propylene monomers connected in a linear chain. This configuration provides several benefits, such as high crystallinity, improved chemical resistance, reduced density, and adequate mechanical strength. Due to these properties, polypropylene is widely used in several areas, such as the automotive, textile, packaging, and construction industries (Guezzout et al., 2023). However, the increase of oil prices and the excessive generation of plastic waste drive the search for more sustainable alternatives. Polypropylene recycling emerges as a promising solution, offering several environmental, economic, and social benefits.

Some authors (Bahij et al., 2020) suggest that plastic waste, such as polypropylene, can be added to concrete to replace part of the aggregates, both coarse and fine fractions. This technique is known as direct volume replacement, where traditional aggregates are directly replaced by alternative materials, such as polymers. Hence, the use of plastic waste for cementitious material brings substantial environmental advantages in addition to improving the characteristics of concrete, such as reducing density, making it possible in some cases to obtain lightweight concrete (Frahat et al., 2024).

Other authors analysed the application of plastic waste, such as PET (Polyethylene terephthalate), in asphalt mixtures, evaluating and proving the viability of applying this material in limited amounts (Baradaran et al., 2024a, 2024b). However, some authors highlight the impossibility of a complete replacement of aggregate with plastic waste in concrete, due to the weak transition zone and the loss of strength of the material. Some authors suggest that the use of plastic waste as a substitute for aggregates should be limited to 25 to 40% (Marvila et al., 2022; Saikia and de Brito, 2012; Sharma and Bansal, 2016). Based on these studies, in this research, the use of 30% of plastic waste as a substitute for conventional coarse aggregate was standardised. Another important point is the need for new methodologies that allow for the improvement of the transition zone between hardened cement paste and aggregate, in the case of plastic waste (Panda et al., 2024).

The experimental hypothesis tested in this study is that the pre-saturation of recycled polypropylene plastic waste aggregates can improve the interfacial transition zone with the cement paste, enhancing the overall performance of the concrete. Three saturation conditions were evaluated: distilled water, cement-saturated water, and silica fume-saturated water. The new approach of this research lies in proposing an alternative methodology for incorporating plastic waste into concrete through saturation techniques, aiming to improve bond characteristics and mechanical behaviour. In line with efforts to promote sustainability in the construction industry, this study investigates the use of recycled plastic waste as a partial aggregate replacement in lightweight concrete. To assess its effectiveness, tests on fresh and hardened concrete were carried out, including workability, density and compressive strength of concrete.

2. MATERIALS AND METHODS

2.1 Materials

The materials used in the research were: Portland cement CP-II-E-32 (NBR 16697, 2018) like CEM-III (BS EN 197-1, 2011); washed river sand with maximum characteristic dimension = 2.4 mm as fine aggregate; gneiss crushed stone with maximum characteristic dimension = 19.00 mm as coarse aggregate; and polypropylene plastic waste obtained from a recycling centre in Belo Horizonte, Brazil (Figure 1). Although other types of cement are available, the choice for CP-II-E-32 is due to its availability and lower associated cost for the production of conventional concrete.

Portland cement from Tupi Cements and silica fume from Tecnosil were used to saturate the aggregate. The chemical composition of the binders used to saturate plastic waste is shown in Table 1. The results were obtained through energy-dispersive X-ray fluorescence (XRF) analysis, conducted using a Shimadzu EDX-700 spectrometer. It is observed that the materials used are similar to other research with cementitious materials (Arash Rajaee et al., 2025; Hadi Miri et al., 2024).

Table 1. Chemical Composition of the Binders Used in the Saturation of Plastic Waste

%	CaO	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	SO_3	MgO	Na_2O	K_2O	Other
Portland Cement	55.75	22.86	9.63	-	2.79	2.73	1.04	0.14	0.48	4.58
Silica fume	1.18	93.85	2.78	-	-	0.44	-	-	0.82	0.93

Figure 1. Polypropylene Plastic Waste Used in Research

2.2 Characterisation of Coarse Aggregates

The plastic waste aggregate and crushed stones (coarse aggregate) were characterised using the following parameters: specific mass (NBR 16972, 2021), Los Angeles abrasion (DNIT ME 035, 1998) from the company ABM Equipment, granulometry (NBR 17054 ,2022) and shape index (NBR 7809, 2014). The characterisation was performed to compare the recycled aggregate and the conventional aggregate.

2.3 Concrete Preparation and Compositions Evaluated

Preparation and Compositions Evaluated The percentage of polypropylene plastic waste used was based on previous studies that resulted in satisfactory compressive strength. According to research (Marvila et al., 2022; Saikia and de Brito, 2012; Sharma and Bansal, 2016) with 30% plastic waste, the compressive strength of the concrete reached its maximum value, since above 30% plastic, there is low adhesion between the hardened cement paste and the plastic waste, impairing its mechanical properties. In this work, it was decided to replace 30% of the mass of natural coarse aggregate with plastic waste and use the composition, by mass, of 1:1.45:2.35:0.55 (Portland cement: fine aggregate: coarse aggregate: water).

To evaluate the influence of polypropylene plastic waste on concrete, five different types of composition were prepared: a reference composition, composed only of conventional aggregates, and four compositions with the addition of plastic waste: dry, saturated with water, saturated with cement, and saturated with silica fume. This diversification of compositions allowed a more comprehensive analysis of the impact of plastic waste on concrete properties, verifying the effect of material saturation. Figure 2 presents a summary of the compositions used in this research.

The procedures used to prepare the concrete were carried out in accordance with NBR 5738 (2015) and NBR 5739 (1994). The concrete was mixed following the procedure: first, the coarse aggregate was added together with half the water (0.275); in cases where plastic waste was used, the aggregate was added at this stage ; then the cement and sand (fine aggregate) were added; followed by the remaining mixing water. The concrete was mixed for 3 minutes. The moulds used had dimensions of 10 cm in diameter and 20 cm in height, using 3 samples for each concrete parameter evaluated. The test specimens were moulded in 2 layers, applying 25 blows with a standard rod. After 24 h, the samples were unmoulded and cured in a 5% $Ca(OH)_2$ aqueous solution. The test evaluations were performed after 28 days of curing.

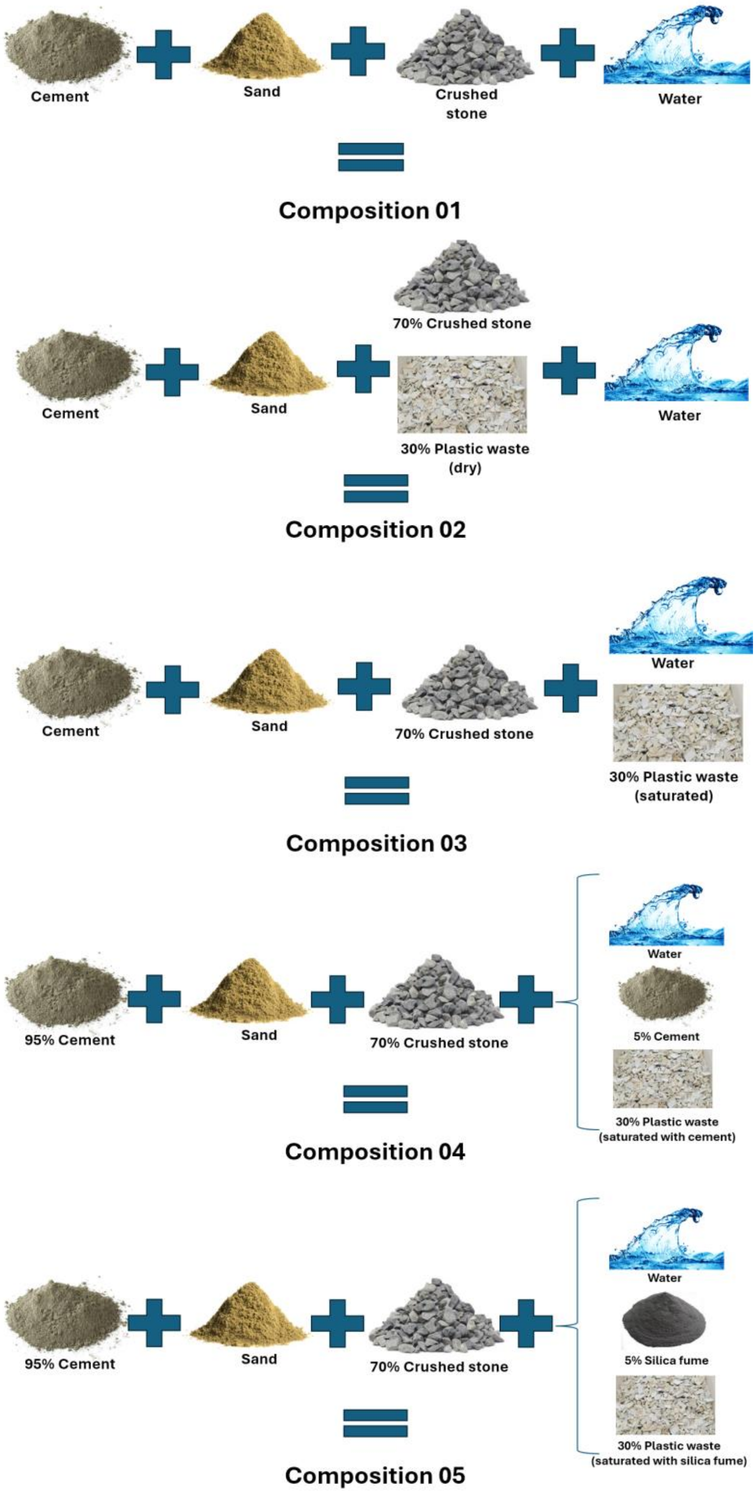

Figure 2. Flowchart of the Compositions Evaluated in the Research

2.4 Properties Evaluated in Concrete

After preparing the concrete, to verify the workability of the newly manufactured material, the slump test was performed in accordance with NBR 16889 (2020). After the 28 day curing period, the specimens were subjected to capillary water absorption and water absorption by immersion test, following the recommendations of NBR 9778 (2011); density in the fresh and hardened state, using the specifications of NBR 9833 (2009); and compressive strength using a universal testing machine INSTRON Series 23.

The capillary water absorption test is performed as follows: the test specimens are dried in an oven at 105ºC for 24 h (m_{dry}) and then subjected to a water layer of approximately 1 cm for 24 h; after this time, the saturated mass (m_{sat}) of the sample is obtained. The immersion water absorption test follows a similar principle, but the samples are completely immersed in water and are fully saturated for 24 h. Water absorption (WA) is then calculated using equation (1). Other studies have performed similar procedures (Hadi Miri et al., 2024).

$$WA = \frac{m_{sat} - m_{dry}}{m_{dry}} * 100 \tag{1}$$

3. RESULTS AND DISCUSSION

Table 2 presents the characterisation parameters of plastic waste aggregate and coarse aggregate used in this study. The shape index is the parameter that presents the largest difference in the results between the aggregates. This is because the gravel has a larger thickness, and the plastic waste has a lamellar shape. The specific mass also presented a large difference in the results between the aggregates; this occurs because the plastic waste is a light aggregate with a specific mass ≤ 2.00 g/cm³. The specific mass of 1.01 g/cm³ of the plastic waste used in the study is close to the value of 0.946 g/cm³ obtained by (Correa et al., 2014). The abrasion of the plastic waste is lower than that of the natural aggregate; therefore, it resists wear better. This occurs due to the lamellar shape, increase in ductility and the properties of the polymer that characterises the plastic waste aggregate (Lim et al., 2024; Uche et al., 2024).

Table 2. Aggregate Parameters

Aggregate	Shape Index	MCD (mm)	FM	Specific mass (g/cm³)	Aggregate abrasion (%)
Crushed stone (coarse aggregate)	2.04	19.00	6.12	2.65	3.60
Plastic Waste	8.17	19.00	6.47	1.01	21.00

MCD = Maximum characteristic dimension

FM = Fineness modulus

Figure 3 shows the particle size distribution of the raw materials used in this research. The coarse aggregate (in red) and the plastic waste (in grey) have similar granulometries. Furthermore, it is worth noting that both conventional coarse aggregate and plastic waste are within the regulatory limits for this type of material, as highlighted in Figure 3 (Upper and Lower limit). This occurs because the MCD is the same for both materials, being 19.00 mm, and the FM has similar values. The materials were chosen by this standard so that there would be no interference in the packaging of the concrete.

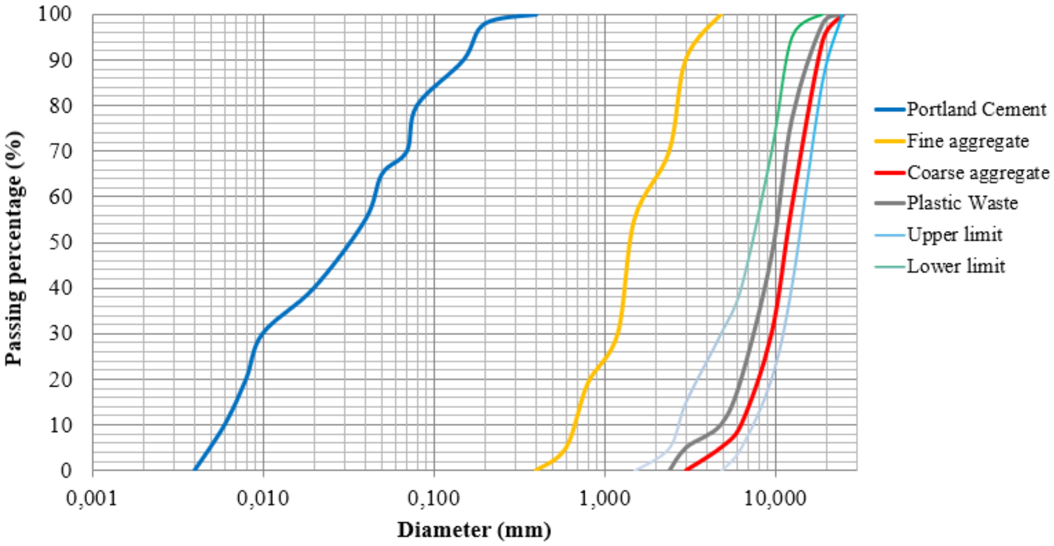

Figure 3. Particle Size Distribution of Materials Used in the Research

Figure 4 shows the results of the slump test of the concrete produced in the research. The concrete containing plastic waste saturated with silica fume showed the best workability, obtaining a slump of 190 mm. This occurs because the silica fume and other pozzolanic materials have a high fineness, reducing the friction of the concrete (Bani Ardalan et al., 2017). In the concrete with the addition of dry plastic waste, saturated with cement and saturated with water, the concrete showed lower workability. It could be observed that saturation with cement increased the adhesion of the aggregate with the concrete, providing an increase in plasticity in relation to the other compositions. The slump of 30 mm with dry plastic waste increased to 35 mm with plastic waste saturated with cement. Saturation with water showed a decrease in the workability of the concrete, showing a slump of 25 mm. This occurs because the smooth surface of the plastic, in contact with water, facilitates the adhesion process between the waste. As highlighted in some studies (Tudu et al., 2024), the reduction in the slump of concrete made with plastic waste is attributed to its shape, which in this study was lamellar, which led to an increase in the porosity of the concrete, resulting in a reduction in its workability. The results obtained are compatible with other research with plastic waste, in which the authors observed a reduction in the slump test from 98 mm (reference) to 56 mm (25%), 43 mm (50%), 20 mm (75%) and 11 mm (100%) in compositions containing coarse aggregates of plastic waste (Mo et al., 2025).

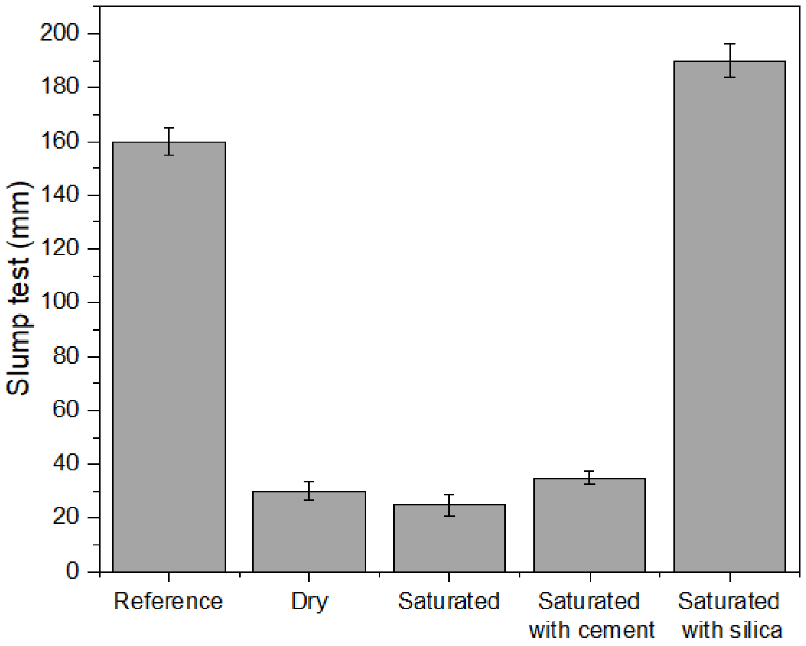

Figure 4. Slump Test Results for the Compositions Evaluated in This Research

Figure 5 shows the water absorption of the test specimens by immersion and capillarity. The addition of dry plastic waste reduces water absorption, where water absorption by capillarity reduces from 2.55% in the reference composition to 1.70% in the composition with dry plastic waste. This occurs because the volume of plastic waste was greater than that of the natural aggregate, reducing the porosity of the concrete and, consequently, its capacity to absorb water. In contrast, the composition with silica fume presents greater water absorption by both test methods, indicating an increase in the porosity of the concrete. The permeability or water transport of concrete is a property that depends on porosity, that is, it indicates the capacity for penetration and absorption of liquids and gases in the concrete (Mendes et al., 2012; Revilla-Cuesta et al., 2024).

Plastic waste saturated with water, cement and silica fume gradually increases water absorption. For example, water absorption results by immersion increase from 2.95% (reference) to 3.47% (saturated with water), 3.93% (saturated with cement) and 4.44% (saturated with silica fume). This characteristic is the result of a decrease in the physical-chemical interaction between the polymer and the cementitious matrix, making the material more susceptible to water penetration due to increased porosity and loss of components through leaching compared to concretes made with natural aggregates (Mendes et al., 2012; Revilla-Cuesta et al., 2024). Although they present greater water absorption, the concrete in this study is classified as durable, since their absorption rates, except for concretes saturated with silica, are below the limit of 4.2%. Concrete saturated with silica, in turn, is classified as normal, with water absorption between 4.2% and 6.2% (Helene, 1983). The water absorption results obtained by immersion are compatible with other research, where the authors obtained an increase in absorption from 2.00% (reference) to 4.1%, 4.6%, 4.8% and 5.10% for compositions containing 10, 15, 20 and 25% of plastic waste, respectively (Lakshmi et al., 2024).

The results of water absorption by capillarity are related to interconnected pores, which maintain a connection between themselves (Marvila et al., 2022b; Yedra et al., 2022). The fact that the composition with dry plastic waste reduces this property indicates that the pores of this concrete are not connected, which can be attributed to the lamellar shape of the plastic waste. Therefore, this is an important result for lightweight concretes, since, due to their lower compressive strength, they are generally less durable. Since the use of dry plastic waste reduces the porosity of the concrete, although there is a drop in strength, this result is viable for application in lightweight concrete.

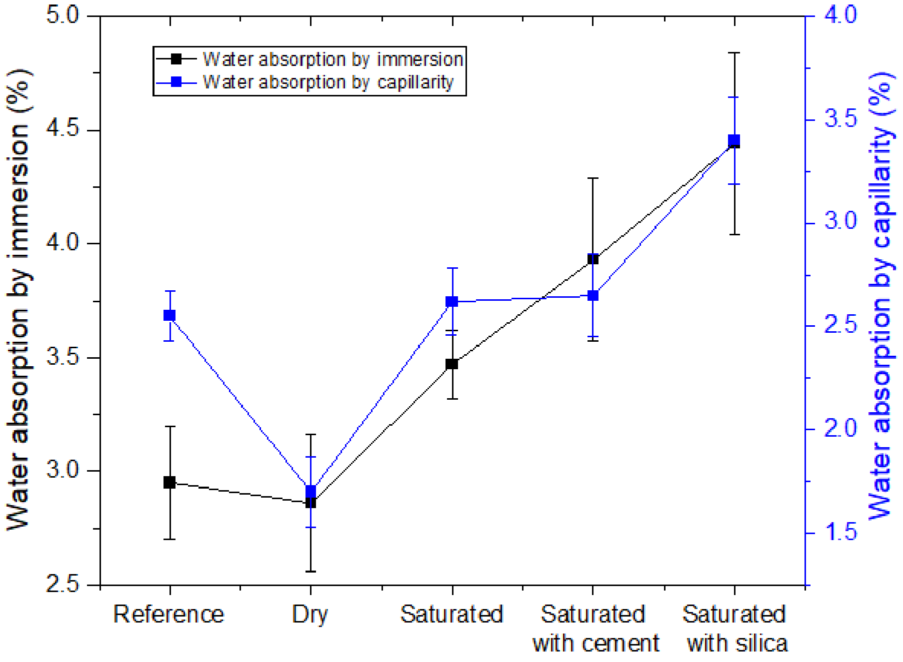

Figure 5. Water Absorption Results for the Compositions Evaluated in This Research

Figure 6 shows the density of the concrete in its fresh and hardened states. The addition of plastic waste decreased the density of the concrete. The density results in the hardened state reduce from 2.30 g/cm³ (reference) to 1.92 g/cm³ (dry waste), 1.83 g/cm³ (saturated with water and cement), and 1.82 g/cm³ (saturated with silica fume). This occurs because the specific mass of the coarse aggregate is greater than that of the plastic waste (Table 2). In the fresh state, the concrete with plastic waste saturated with water had a lower density when compared to the reference composition. This occurs because, when the plastic waste is saturated with water, it can retain this water internally, reducing the amount of free water available in the concrete mix. In the hardened state, the lower density is due to saturation with silica fume, when compared to the reference composition. This occurs because this composition has greater water absorption (Figure 5) and probably greater porosity and voids. In its hardened state, concrete with the addition of plastic waste has a density of less than 2000 kg/m³ (Ahmadi et al., 2023; Pongsopha et al., 2022), being classified as lightweight concrete according to another research (ASTM C567/C567M-19, 2019). In other studies, with concrete containing plastic waste (Correa et al., 2014; Frahat et al., 2024), lightweight concrete was also obtained with the addition of polypropylene.

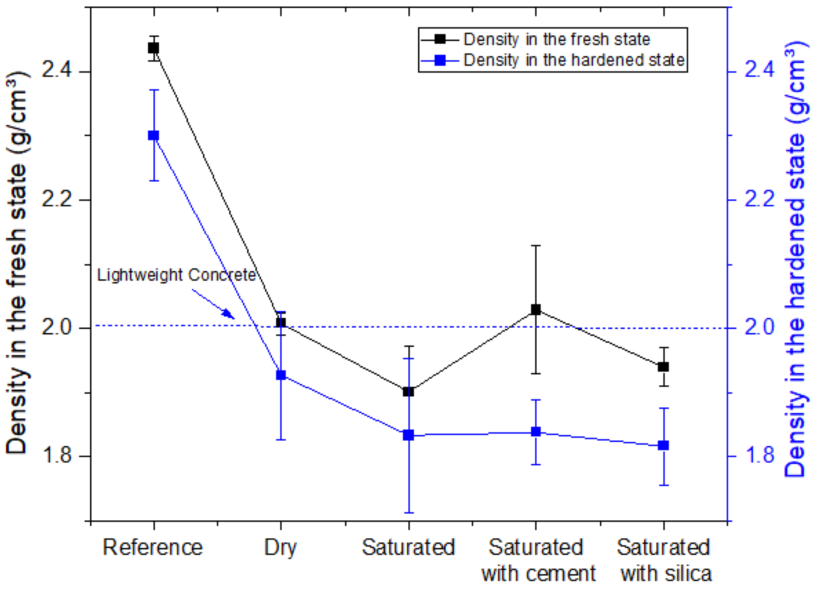

Figure 6. Density Results for the Compositions Evaluated in This Research

Figure 7 shows the axial compressive strength. The addition of plastic waste saturated with silica presented lower strength (6.24 MPa). Compared to the reference value, whose compressive strength is 22.60 MPa, this represents a reduction of 72.4%. This is due to the increase in the porosity of the concrete, causing greater water absorption (Figure 5). In contrast, the composition with dry plastic waste presented greater compressive strength, since this composition has less porosity and, consequently, less water absorption (Figure 5). The decrease in compressive strength was also observed in other studies (Tapkire et al., 2014), which replaced part of the coarse aggregate with waste from plastic bags (polypropylene) and soda bottles (PET).

Water absorption is directly related to the compressive strength obtained in the compositions with the addition of plastic waste in this study. This occurs because the porosity of a material exerts a significant influence on its strength and durability, as evidenced by the relationship between compressive strength and water/cement ratio (Marvila et al., 2020). In the case of concrete, especially those with the addition of recycled materials, the presence of interconnected pores creates preferential pathways for the penetration of water and other aggressive agents that can cause deterioration. Concrete with a lower porosity index, in turn, offers greater resistance to the penetration of these agents, contributing to a longer useful life of the structure.

The decrease in concrete strength is due to the lower chemical interaction between the polymer and the cementitious matrix and the residual porosity generated in the production of the sample (Correa et al., 2014). As highlighted by some authors (Neville, 2015), as the strength and specific mass of the aggregates used in the production of conventional concrete increases, the influence of these aggregates on the compressive strength of the concrete decreases, since the strength of the aggregates becomes greater than that of the matrix. Therefore, when adding polypropylene waste to concrete, a decrease in compressive strength is observed. Furthermore, the lower strength of concrete with recycled aggregate can be explained by the reduced adhesion between the cement paste and the aggregate, caused by the lamellar shape and smooth appearance of the aggregate. Furthermore, the lower modulus of elasticity of recycled aggregate compared to conventional aggregate reduces its ability to resist compressive strength (Haigh, 2024; Mouzoun et al., 2023). Other authors obtained similar results: (Khan et al., 2025) obtained a reduction in compressive strength from 22 MPa (reference) to 10.5 MPa (composition with 100% plastic waste); (Edike et al., 2024) obtained a reduction in compressive strength from 22.78 MPa (reference) to 10.36 MPa (composition with 25% plastic waste).

Based on previous research (Bideci et al., 2023; Ghone et al., 2024; Pongsopha et al., 2022), a minimum compressive strength value of 10 MPa was defined for lightweight concrete. This type of concrete is used in sealing and for thermal and acoustic insulation. Therefore, it is observed that the composition that best meets the defined parameters is the one that contains dry plastic waste, with a compressive strength of 12.23 MPa.

On the other hand, the concrete compositions produced with plastic waste saturated with cement and silica fume, although presenting low compressive strength, demonstrate low density (Figure 6), good workability parameters (Figure 4), especially the composition saturated with silica fume, and high water absorption (Figure 5). This indicates that these concrete compositions are permeable and porous, being viable in applications where it is necessary to allow the passage of water through their structure, such as urban drainage and/or draining pavements.

In practical terms, the results of this research highlight that the composition produced with dry plastic waste has important applications as concrete for insulation, while the compositions saturated with cement and silica fume represent a viable alternative for concrete used in drainage systems.

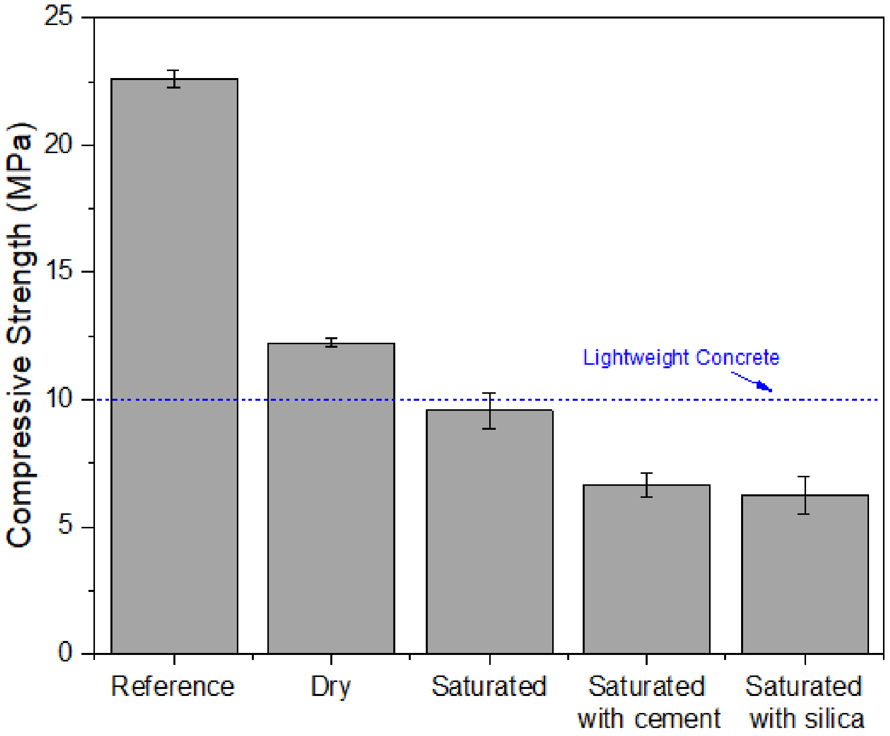

Figure 7. Compressive Strength Results for the Compositions Evaluated in This Research

Figure 8 shows the crack pattern of reference compositions and those with dry plastic waste. The reference composition presents a crack pattern similar to cementitious materials, with inclined cracks, suggesting shear fracture. In the case of the dry plastic waste composition, fracture with outcropping of plastic waste is observed, which is an indication of the deficiency of the transition zone between aggregate and hardened cement paste. Thus, the methodology proposed in this research was not sufficient to promote greater adhesion between the plastic waste and the cement paste, although the objective of obtaining lightweight concrete was achieved.

(a) (b)

Figure 8. Fracture/Crack Pattern: (a) reference composition; (b) composition with dry plastic waste

4. CONCLUSIONS

Polypropylene plastic waste was tested as recycled aggregate in this research to reduce the consumption of coarse aggregate used in concrete. The recycled aggregate was evaluated with different preparations (dry, saturated with water, cement and silica fume). The slump test, density, water absorption and compressive strength parameters were evaluated. Given the results presented, it is possible to conclude:

- The use of plastic waste as aggregate in concrete, in addition to helping preserve limited natural resources, favours the production of lightweight concrete with lower specific masses. However, the lamellar shape and smoothness of the aggregate cause less chemical interaction between the polymer and the cement matrix, resulting in increased porosity, higher water absorption rates, higher void indices and, consequently, lower compressive strength.
- The compressive strength of the concrete containing plastic waste showed lower values than those obtained for the reference concrete; on the other hand, the composition containing dry plastic waste showed satisfactory mechanical strength results for lightweight concrete, with results of 12.23 MPa, higher than the value of 10 MPa indicated for insulation concrete.
- The initial hypothesis defined in this research, that the use of saturation in plastic aggregates would improve the transition zone, was not verified in this research. On the contrary, the presence of water at the interface of the recycled aggregate from plastic waste reduced adhesion, impairing compressive strength and increasing water absorption. This occurs because plastic waste has low water absorption; therefore, there is no water impregnation in the residue that improves adhesion with the cement paste.

As a suggestion for future work, it is recommended: (i) to evaluate other concrete parameters, such as electrical resistivity, thermal and acoustic insulation, to prove the viability of applying concrete as insulation; (ii) to perform non-destructive tests on the concrete, such as ultrasound and rebound hammer; (iii) to evaluate other mechanical properties, such as flexural strength and modulus of elasticity; (iv) to evaluate other percentages of incorporation of plastic waste, such as 20% or 50%; (v) to evaluate other forms of saturation of the plastic aggregate, using other pozzolanic materials, such as metakaolin and fly ash, or other binders, such as hydrated lime; (vi) evaluation of the microstructure to characterise the interface between hardened cement paste and aggregate, using scanning electron microscopy (SEM), microtomography and mercury intrusion porosimetry (MIP) analysis.

AUTHOR CONTRIBUTIONS

Nathália Pereira Soares: Original draft, Visualisation, Methodology, Investigation.
Marília Gonçalves Marques: Original draft, Visualisation, Methodology, Investigation.
Leonardo Carvalho Mesquita: Review & Editing, Methodology, Funding acquisition, Conceptualisation.
Afonso Rangel Garcez de Azevedo: Review & Editing, Methodology, Investigation, Conceptualisation.
Markssuel Teixeira Marvila: Review & Editing, Project administration, Methodology, Funding acquisition, Conceptualisation.

DECLARATIONS

Competing interests The authors declare no competing interests.

REFERENCES

ABNT, 1994. NBR 5739: Compression tests of cylindrical specimens. Associação Brasileira de Normas Técnicas.

ABNT, 2009. NBR 9833: Fresh concrete - Determination of specific mass, yield and air content by the gravimetric method. Associação Brasileira de Normas Técnicas.

ABNT, 2011. NBR 9778: Hardened mortar and concrete - Determination of water absorption, void index and specific mass. Associação Brasileira de Normas Técnicas.

ABNT, 2014. NBR 7809: Coarse aggregate — Determination of shape index by the vernier caliper method — Test method. Associação Brasileira de Normas Técnicas.

ABNT, 2015. NBR 5738: Concrete – Procedure for molding and curing test specimens. Associação Brasileira de Normas Técnicas.

ABNT, 2018. NBR 16697: Portland Cement — Requirements. Associação Brasileira de Normas Técnicas.

ABNT, 2020. NBR 16889: Concrete — Determination of consistency by slumping of the truncated cone. Associação Brasileira de Normas Técnicas.

ABNT, 2021. NBR 16972: Aggregates – Determination of unit mass and void volume. Associação Brasileira de Normas Técnicas.

ABNT, 2022. NBR 17054: Aggregates - Determination of particle size composition - Test method. Associação Brasileira de Normas Técnicas.

Ahmadi, S.F., Reisi, M., Sajadi, S.M., 2023. Comparing properties of foamed concrete and lightweight expanded clay aggregate concrete at the same densities. Case Studies in Construction Materials 19, e02539. https://doi.org/10.1016/j.cscm.2023.e02539

Arash Rajaee, Mohammadreza Sadeghzadeh, Morteza Shekhi, Mohammadsadra Yousefi, 2025. Enhancing the Mechanical Properties of Sawdust Concrete with Silica Fume, Metakaolin, and Marble Powder. Journal of Civil Aspects and Structural Engineering 2, 1–13.

ASTM C567/C567M-19, 2019. Standard Test Method for Determining Density of Structural Lightweight Concrete. ASTM International 04.

Bahij, S., Omary, S., Feugeas, F., Faqiri, A., 2020. Fresh and hardened properties of concrete containing different forms of plastic waste – A review. Waste Management 113, 157–175. https://doi.org/10.1016/j.wasman.2020.05.048

Bani Ardalan, R., Joshaghani, A., Hooton, R.D., 2017. Workability retention and compressive strength of self-compacting concrete incorporating pumice powder and silica fume. Constr Build Mater 134, 116–122. https://doi.org/10.1016/j.conbuildmat.2016.12.090

Baradaran, S., Aliha, M.R.M., Maleki, A., Underwood, B.S., 2024a. Fracture properties of asphalt mixtures containing high content of reclaimed asphalt pavement (RAP) and eco-friendly PET additive at low temperature. Constr Build Mater 449, 138426. https://doi.org/10.1016/j.conbuildmat.2024.138426

Baradaran, S., Rahimi, J., Ameri, M., Maleki, A., 2024b. Mechanical performance of asphalt mixture containing eco-friendly additive by recycling PET. Case Studies in Construction Materials 20, e02740. https://doi.org/10.1016/j.cscm.2023.e02740

Bideci, A., Bideci, Ö.S., Ashour, A., 2023. Mechanical and thermal properties of lightweight concrete produced with polyester-coated pumice aggregate. Constr Build Mater 394, 132204. https://doi.org/10.1016/j.conbuildmat.2023.132204

BS EN 197-1, 2011. BS EN 197-1. Materiales de Construccion 62.

Chen, L., Huang, L., Hua, J., Chen, Z., Wei, L., Osman, A.I., Fawzy, S., Rooney, D.W., Dong, L., Yap, P.-S., 2023. Green construction for low-carbon cities: a review. Environ Chem Lett 21, 1627–1657. https://doi.org/10.1007/s10311-022-01544-4

Chiang, Y.H., Tao, L., Wong, F.K.W., 2015. Causal relationship between construction activities, employment and GDP: The case of Hong Kong. Habitat Int 46, 1–12. https://doi.org/10.1016/j.habitatint.2014.10.016

Correa, P.M., Fernando, L., Júnior, R., 2014. Obtention of lightweight concrete: a study on the addition of polymer with functional groups (PET) and without functional groups (PP). Disciplinarum Scientia 15, 99–109.

DNIT ME 035, 1998. Aggregates - Determination of “Los Angeles” Abrasion. Departamento Nacional De Estradas De Rodagem.

Edike, U.E., Ameh, O.J., Yohanna, H.S., Osuizugbo, I.C., Nduka, D.O., 2024. Mechanical Properties of Concrete Blocks Incorporating Recycled Waste Plastic. Materials Circular Economy 6, 10. https://doi.org/10.1007/s42824-024-00101-4

Ehsan Farahinia, Morteza Sheikhi, Davarpanah Tanha Quchan Amirhossein, Arash Rajaee, Morteza Ghodratnama, Seyed Mostafa Banihashem, Pooyan Pournoori, 2024. Experimental and numerical exploration of mechanical properties of sawdust concrete due to the addition of waste glass powder. International Journal of Sustainable Building Technology and Urban Development 328–353.

Frahat, N.B., Malek, A.S., Ali, A., Ibrahim, O.M.O., 2024. New strategy for closing the plastic loop: Lightweight concrete by the waste of recycled synthetic fibers. Constr Build Mater 423, 135896. https://doi.org/10.1016/j.conbuildmat.2024.135896

Ghone, M.O., Long, G., Yang, K., Ma, X., Islam, N., 2024. Toughness improvement of low strength ceramsite lightweight concrete by polypropylene fiber and recycled rubber particle. Constr Build Mater 422, 135716. https://doi.org/10.1016/j.conbuildmat.2024.135716

Guezzout, Z., Boublia, A., Haddaoui, N., 2023. Enhancing thermal and mechanical properties of polypropylene-nitrile butadiene rubber nanocomposites through graphene oxide functionalization. Journal of Polymer Research 30, 207. https://doi.org/10.1007/s10965-023-03585-x

Hadi Miri, Arash Rajaee, Morteza Ghodratnama, Amirhossein Davarpanah Tanha QuchanMorteza Sheikhi, Morteza Sheikhi, Pooyan Pournoori, 2024. Experimental and numerical investigation on water absorption and strength of lightweight concrete containing LECA and cold bitumen powder. International Journal of Sustainable Building Technology and Urban Development 15, 307–327.

Haigh, R., 2024. The mechanical behaviour of waste plastic milk bottle fibres with surface modification using silica fume to supplement 10% cement in concrete materials. Constr Build Mater 416, 135215. https://doi.org/10.1016/j.conbuildmat.2024.135215

Helene, P.R. do L., 1983. The Aggression of the Medium and the Durability of the Hormigón. Hormigón. Asociación Argentina de Tecnología del Hormigón 25–35.

Khan, H., Ahmad, J., Zahid, Z. Bin, Irfan, S., Umer, M., 2025. Development of extrusion based artificial lightweight aggregates from sand-plastic waste composite for sustainable concrete production: Performance evaluation and Life Cycle Assessment. Case Studies in Construction Materials 22, e04663. https://doi.org/10.1016/j.cscm.2025.e04663

Lakshmi, R., Sowmiyavalli, R., Arunprasath, K., Rajpradeesh, T., 2024. Sustainable waste management options of waste plastic particles in cementitious mixtures for mass concrete applications. Interactions 245, 340. https://doi.org/10.1007/s10751-024-02164-w

Lim, S.M., He, M., Hao, G., Ng, T.C.A., Ong, G.P., 2024. Recyclability potential of waste plastic-modified asphalt concrete with consideration to its environmental impact. Constr Build Mater 439, 137299. https://doi.org/10.1016/j.conbuildmat.2024.137299

Mahdi Amirnia, Morteza Sheikhi, Nafiseh Talebi, Pooyan Pournoori, Arash Rajaee, 2024. Evaluation of hardened properties of structural concrete containing waste tiles and volcanic ash, in: 5th. International Congress on Engineering, Technology & Applied Sciences. Auckland, New Zealand, pp. 1–12.

Marvila, M., de Matos, P., Rodríguez, E., Monteiro, S., de Azevedo, A., 2022. Recycled Aggregate: A Viable Solution for Sustainable Concrete Production. Materials 15, 5276. https://doi.org/10.3390/ma15155276

Marvila, M.T., Azevedo, A.R.G., Monteiro, S.N., 2020. Verification of the application potential of the mathematical models of lyse, abrams and molinari in mortars based on cement and lime. Journal of Materials Research and Technology 9, 7327–7334. https://doi.org/10.1016/j.jmrt.2020.04.077

Marvila, M.T., de Azevedo, A.R.G., Ferreira, R.L.S., Vieira, C.M.F., de Brito, J., Adesina, A., 2022. Validation of alternative methodologies by using capillarity in the determination of porosity parameters of cement-lime mortars. Mater Struct 55, 19. https://doi.org/10.1617/s11527-021-01877-6

Mendes, A., Sanjayan, J.G., Gates, W.P., Collins, F., 2012. The influence of water absorption and porosity on the deterioration of cement paste and concrete exposed to elevated temperatures, as in a fire event. Cem Concr Compos 34, 1067–1074. https://doi.org/10.1016/j.cemconcomp.2012.06.007

Mo, Z., Zhang, X., Wang, Y., Guo, F., Gao, X., 2025. Combination of waste plastic and coal gangue as coarse aggregates applied into concrete blended with metakaolin. Constr Build Mater 471, 140732. https://doi.org/10.1016/j.conbuildmat.2025.140732

Mouzoun, K., Bouyahyaoui, A., Cherradi, T., Zemed, N., Simou, S., 2023. From waste to strength: Experimental design and optimization of mechanical properties of concrete using reused PVC-U drainage pipes. Constr Build Mater 401, 132938. https://doi.org/10.1016/j.conbuildmat.2023.132938

Neville, A.M., 2015. Properties of Concrete, 5th ed. Bookman, São Paulo.

Nguyen, T.T., Edalati, K., 2024. Impact of high-pressure torsion on hydrogen production from photodegradation of polypropylene plastic wastes. Int J Hydrogen Energy 81, 411–417. https://doi.org/10.1016/j.ijhydene.2024.07.306

Panda, S., Nanda, A., Panigrahi, S.K., 2024. Potential utilization of waste plastic in sustainable geopolymer concrete production: A review. J Environ Manage 366, 121705. https://doi.org/10.1016/j.jenvman.2024.121705

Pongsopha, P., Sukontasukkul, P., Zhang, H., Limkatanyu, S., 2022. Thermal and acoustic properties of sustainable structural lightweight aggregate rubberized concrete. Results in Engineering 13, 100333. https://doi.org/10.1016/j.rineng.2022.100333

Pournoori, P., Davarpanah T.Q., A., Rajaee, A., Ghodratnama, M., Abrishami, S., Masoodi, A.R., 2024. Experimental exploration of fracture behavior (pure mode III) in eco-friendly steel fiber-reinforced self-compacting concrete with waste tempered glass as coarse aggregates. Sci Rep 14, 9043. https://doi.org/10.1038/s41598-024-58912-z

Qabaja, M., Tenekeci, G., 2024. Influence of inflation on the construction sector and economic growth in selected countries: A continental comparison. Ain Shams Engineering Journal 103013. https://doi.org/10.1016/j.asej.2024.103013

Revilla-Cuesta, V., Faleschini, F., Pellegrino, C., Skaf, M., Ortega-López, V., 2024. Water transport and porosity trends of concrete containing integral additions of raw-crushed wind-turbine blade. Developments in the Built Environment 17, 100374. https://doi.org/10.1016/j.dibe.2024.100374

Rosato, D., 2020. Polypropylene Performance Developments Move Forward! Omnexus.

Saikia, N., de Brito, J., 2012. Use of plastic waste as aggregate in cement mortar and concrete preparation: A review. Constr Build Mater 34, 385–401. https://doi.org/10.1016/j.conbuildmat.2012.02.066

Santhosh, K.G., Subhani, S.M., Bahurudeen, A., 2021. Cleaner production of concrete by using industrial by-products as fine aggregate: A sustainable solution to excessive river sand mining. Journal of Building Engineering 42, 102415. https://doi.org/10.1016/j.jobe.2021.102415

Sharma, R., Bansal, P.P., 2016. Use of different forms of waste plastic in concrete – a review. J Clean Prod 112, 473–482. https://doi.org/10.1016/j.jclepro.2015.08.042

Shen, W., Wu, J., Du, X., Li, Z., Wu, D., Sun, J., Wang, Z., Huo, X., Zhao, D., 2022. Cleaner production of high-quality manufactured sand and ecological utilization of recycled stone powder in concrete. J Clean Prod 375, 134146. https://doi.org/10.1016/j.jclepro.2022.134146

Tapkire, G., Parihar, S., Patil Pramod, Kumavat, H.R., 2014. Recycled plastic used in concrete paver block. Int J Res Eng Technol 03, 33–35. https://doi.org/10.15623/ijret.2014.0321009

Tudu, C., Mohanty, M., Mohapatra, S.S., Nayak, S., 2024. A systematic review exploring the feasibility of waste plastic as different constituents towards sustainable concrete. Constr Build Mater 428, 136210. https://doi.org/10.1016/j.conbuildmat.2024.136210

Uche, C.K.A., Abubakar, S.A., Nnamchi, S.N., Mundu, M.M., 2024. Characterization of heat-processed artificial lightweight aggregates from polyethylene terephthalate plastic waste. Discover Civil Engineering 1, 40. https://doi.org/10.1007/s44290-024-00046-2

Yan, W.-C., Dong, T., Zhou, Y.-N., Luo, Z.-H., 2023. Computational modeling toward full chain of polypropylene production: From molecular to industrial scale. Chem Eng Sci 269, 118448. https://doi.org/10.1016/j.ces.2023.118448

Yedra, E., Ferrández, D., Morón, C., Saiz, P., 2022. New test methods to determine water absorption by capillarity. Experimental study in masonry mortars. Constr Build Mater 319, 125988. https://doi.org/10.1016/j.conbuildmat.2021.125988