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Concrete with incorporation of polymeric recycled aggregate

Hormigón con incorporación de agregado reciclado polimérico

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Abstract

This study aims to evaluate the properties of a concrete with polymeric glue residue aggregate, through formulations by replacing natural coarse aggregate (NCA) with polymeric coarse aggregate (PCA). The gradual increase in the PCA content resulted in a reduction in consistency, specific gravity, compressive and flexural strength. However, there was an increase in the void ratio and water absorption. Regarding durability, the partial replacement of 40% of NCA by PCA showed the best performance. The conclusion is that it is possible to use polymer glue waste as aggregate in the production of concrete, helping to reduce the extraction of raw materials and the pollution of this waste in the environment. Its use in concrete production can increase the durability of this material, which will reduce building maintenance.

Keywords: Concrete; Recycled aggregate; Polymeric residue; Sustainable materials.

Resumen

Este estudio tiene como objetivo evaluar las propiedades de un hormigón con agregado de residuos de pegamento polimérico, mediante formulaciones que reemplazan el agregado grueso natural (AGN) por agregado grueso polimérico (AGP). El aumento gradual en el contenido de AGP resultó en una reducción en la consistencia, gravedad específica, resistencia a la compresión y flexión. Sin embargo, hubo un aumento en el índice de vacíos y la absorción de agua. En cuanto a la durabilidad, la sustitución parcial del 40% de AGN por AGP mostró el mejor desempeño. La conclusión es que es posible utilizar residuos de pegamento polimérico como agregado en la producción de hormigón, contribuyendo a reducir la extracción de materias primas y la contaminación de estos residuos en el medio ambiente. Su uso en la producción de hormigón puede aumentar la durabilidad de este material, lo que reducirá el mantenimiento de las edificaciones.

Keywords: Concreto; Agregado reciclado; Residuo polimérico; Materiales sostenibles.

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1. Introduction

Concrete is widely used in construction, comprising approximately 65-70% natural aggregates (Faraj et al., 2019). The extraction of these aggregates has resulted in significant environmental concerns, including ecosystem disruption, soil and air pollution, and substantial CO_2 emissions from quarrying and energy consumption (Al-Mansour et al., 2022). Furthermore, the over-extraction of natural aggregates has led to the depletion of these reserves, exacerbating the environmental impact (Sebsadji, 2022).

Population growth contributed to the development of infrastructure, which also caused a high exploitation of natural resources to meet the demand for raw materials in civil construction. Studies (Záleská et al., 2018) have shown that there are several waste options as substitutes for conventional aggregates, which can effectively reduce the environmental impacts promoted by civil construction and industries.

According to the report by the World Wide Fund for Nature (2019), Brazil is the fourth country worldwide in polymers production, with 11.3 million tons produced per year. 91% of this production is collected, but only 145 thousand tons are recycled, corresponding to 1.28% of the total. Polymer is a material that allows its safe disposal, due to its wide variety of products on the market and characteristics such as durability, processability, low cost, low density, and non-toxicity.

Therefore, large amounts of this polymeric material can be collected and treated to obtain a lighter and recycled aggregate for concrete. Researches, such as that produced by Jacob-Vaillancourt and Sorelli, (2018), precisely propose the usage of polymers as an aggregate to produce concrete, with the most frequently used types, like polyethylene terephthalate (PET), polypropylene (PP), polyethylene (PE), polyvinyl chloride (PVC) and polycarbonate (PC).

Studies have demonstrated the advantages of partially replacing natural aggregates with recycled polymer waste. Among those, the reduction in the weight of concrete, due to the low specific mass of the polymer structure, compared to natural aggregates (Basha et al., 2020); the minimum variation in the consistency of polymeric concrete; the reduction of visual degradation and loss of mass in aggressive environments (Wongkvanklom et al., 2021), (Coppola et al., 2016), (Dulsang et al., 2016).

Algahtani, (2022) based itself on the use of manufactured polymeric aggregate to replace lightweight concrete aggregate. The results obtained in the concrete mixtures, incorporating the manufactured polymeric aggregate, showed a ductile behavior and suggested a replacement level of up to 25% by volume. This percentage minimally compromised the mechanical properties of lightweight concrete. Olofinnade et al., (2021) observed that the use of polymeric residues in the proportion of 10% to produce high-resistance lightweight concrete is very similar to the strength of lightweight concrete produced with conventional materials.

Despite the significant number of studies carried out on the incorporation of polymeric residues in the production of concrete, there is a lack of research that contemplates the type of waste used in this study: polymeric glue residue, of the polyurethane type. Furthermore, this work seeks to meet the objectives of the 2030 Agenda for Sustainable Development presented by the United Nations (UN) and the possible issues that may arise when this concept is not considered in different work areas.

Among the actions that the construction sector can collaborate on for sustainable development, the incorporation of waste for the production of materials contributes directly to various objectives of this agenda, such as poverty eradication, access to clean water and sanitation, affordable and clean energy, industry, innovation, and infrastructure, sustainable cities and communities, sustainable consumption and production, action against climate change, life below water, and life on land. Therefore, this study is of fundamental relevance, as more sustainable practices in the construction industry are aligned with the global goals of reducing the extraction of natural resources, CO2 emissions, and waste disposal in landfills, to contribute to the Net Zero 2050 target.

Therefore, the present research aims to produce concrete with recycled polymeric glue aggregate, replacing natural coarse aggregate, to analyze physical and mechanical properties, together with the durability of these concretes.

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2. Experimental investigation

2.1 Raw material

The cement used in this study was a Portland one, composed of carbonate material (CPII-F-32). Its physical and mechanical properties (Table 1) met the requirements specified in ABNT NBR 16697 (2018).

Table 1. Cement properties.

	Normal consistency (water)	*Fineness index*	*Initial setting time*	*Soundness by Le Chatelier test*	*Specific gravity*	*Compressive strength (28 days)*
Cement	*30%*	*5.4%*	*144 min*	*1.20 mm*	*3.08 g/cm³*	*36,7 MPa*

The natural fine aggregate (NFA) used was natural sand with a fineness modulus of 2.17. The adopted natural coarse aggregate (NCA) and polymeric coarse aggregate (PCA) had a maximum diameter of 19 mm. The aggregates used in this research have a well-graded granulometric distribution (Figure 1) in accordance with NBR 7211 (ABNT 2022).

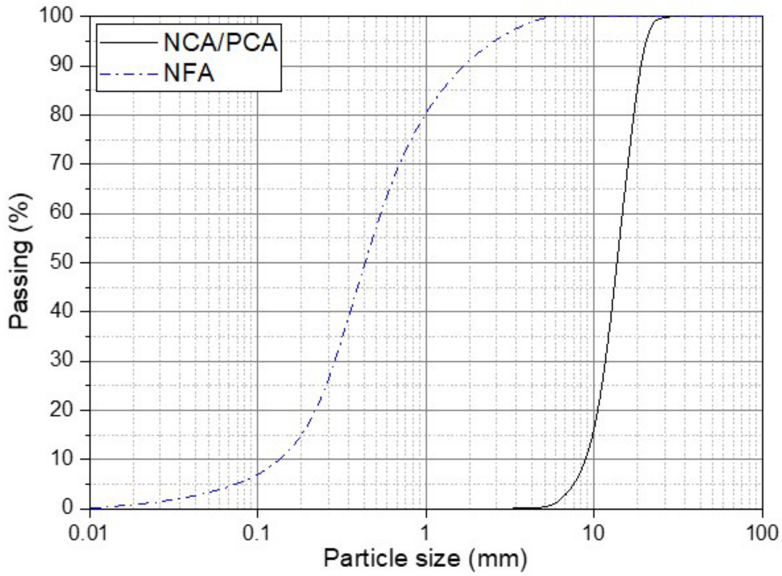

Figure 1. Granulometric distribution.

The properties of the adopted aggregates are presented in (Table 2). The polymeric coarse aggregate is shown in (Figure 2). The PCA used originates from the residue of polymeric glue (Jowatherm Reaktant 605.20), based on polyurethane (thermosetting polymer), used in the bonding of wooden doors at the FAMOSSUL factory, located in the municipality of Estância-SE.

Table 2. Physical characterization of aggregate.

	Maximum size	*Fineness modulus*	*Specific gravity*	*Apparent specific gravity*	*Water absorption*	*Air void content*
NFA	*2.36 mm*	*2.17*	*2.67 g/cm³*	*1702 kg/m³*	*0.5%*	*36%*
NCA	*19 mm*	*6.93*	*2.61 g/cm³*	*1443 kg/m³*	*0.4%*	*45%*
PCA	*19 mm*	*6.93*	*1.08 g/cm³*	*490 kg/m³*	*0%*	*54%*

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Figure 2. Polymeric coarse aggregate.

The hardened residues of polymeric glue were granulated using a steel mesh crusher belonging to the Ouro Plastic recycling plant in the same municipality. After this process, the residue was sieved and the granulometric correction was carried out in the distribution range (9.5/25), according to (Table 6) of NBR 7211 (ABNT, 2022), to be used as a substitute for natural coarse aggregate (NCA). In addition, a plasticizer additive (Maximent NT 19) was used to provide greater fluidity to the mixture for a lower water-cement ratio.

The polymeric glue residue was characterized by the Fourier Transform Infrared Spectroscopy (FTIR) technique. The results obtained, presented in (Figure 3), show the polyurethane spectrum, with a complex arrangement that contains in its composition a frequency of 1218 cm-1 of CO, 3600 cm-1 of NH and 1600 cm-1 of aromatics (Gama et al., 2020), (Gharib et al., 2020).

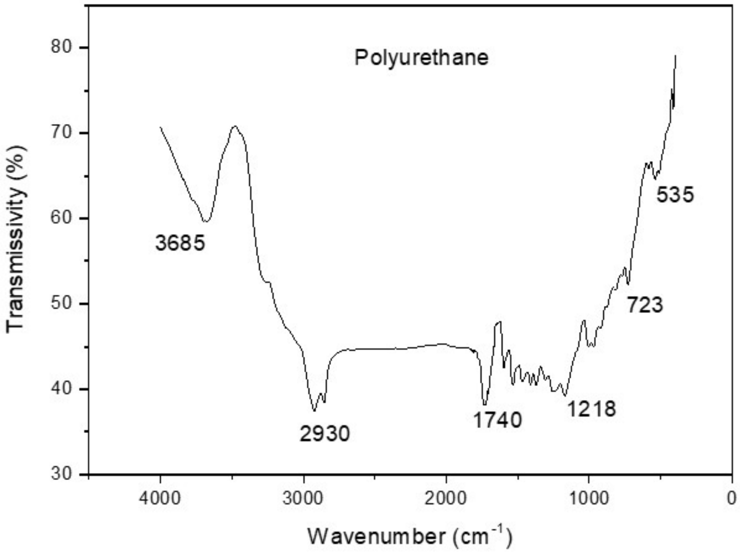

Figure 3. Infrared spectrum of polyurethane glue residue.

2.1.1 Mix proportioning and moulding

To explore the properties of polymeric aggregate concrete, a control concrete dosage formulation of 1:1.76:2.82:0.46 (cement: fine aggregate: coarse aggregate: water) was defined for a compressive strength of 30 MPa, at 28 days. For the other concrete formulations, the replacement in the volume of NCA by PCA and its nomenclatures for the samples were adopted, in 10% (CAP10), 20% (CAP20), 30% (CAP30), and 40% (CAP40). (Table 3) shows the compositions of the materials studied during the production of the concretes.

After mixing, the consistency of each formulation was determined. Once this stage was completed, the initial curing process was awaited, respecting the period of 24 hours. Then, the samples were identified and stored in a saturated lime solution for 28 days. Cylindrical samples (10 cm diameter and 20 cm height) were used for the specific gravity, void ratio and water absorption test, compressive strength test, and durability test. Prismatic samples (100 mm x 100 mm x 400 mm) were used for the flexural strength test SEM.

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Table 3. Mix proportion for concrete (kg/m³).

Concrete	*Cement*	*NFA*	*NCA*	*PCA*	*Water*	*Plasticizer*
CTL	*396.1*	*697.2*	*1117.1*	-	*182.2*	*2.0*
CAP10	*396.1*	*697.2*	*1005.4*	*35.0*	*182.2*	*2.0*
CAP20	*396.1*	*697.2*	*893.7*	*70.0*	*182.2*	*2.0*
CAP30	*396.1*	*697.2*	*782.0*	*105.0*	*182.2*	*2.0*
CAP40	*396.1*	*697.2*	*670.3*	*140.0*	*182.2*	*2.0*

2.1.2 Experimental tests

In the fresh state, the tests were implemented in accordance with the standards "Determination of consistency by slump test" by NBR 16889 (ABNT, 2020) and "Determination of the unit weight, yield and air content by the gravimetric test method" by NBR 9833 (ABNT, 2009). The tests carried out in the hardened state were implemented according to the standards "Determination of absorption, voids and specific gravity" by NBR 9778 (ABNT, 2009), "Compression test of cylindrical specimens" by NBR 5739 (ABNT, 2018), "Determination of tension strength in flexure of prismatic specimens" by NBR 12142 (ABNT, 2010) and the "American Society for Testing Materials" by C267-20 (ASTM, 2020), using the aggressive solution indicated in the standard "Determining of volumetric change of Portland cement mortar bars exposed to sodium sulfate solution" by NBR 13583 (ABNT, 2014) for the durability property.

2.1.3 Data processing and analysis methodology

The data obtained during the concrete characterization tests were presented considering the arithmetic mean of the samples, by formulation, followed by the standard deviation. To evaluate the results obtained in the tests was performed the analysis of variance (ANOVA) methodology, adopting a probability of significance (p-value) less than or equal to 0.05 ($p \leq 0.05$), followed by the Tukey Test, which evaluates significant differences between formulations.

3. Results and discussion

In (Table 4), the results of the analysis of variance methodology for all evaluated properties are presented. Significant variations were observed (F > critical F and p-value <0.05), and through the Tukey Test, the following sections will present which formulations these significant differences were observed.

Table 4. Results of the analysis of variance methodology.

Properties	*F*	*critical F*	*p-value*
Consistency	*13.375*	*5.19*	$7.019x10^{-3}$
Specific gravity	*88.86*	*3.06*	$2.94x10^{-10}$
Void ratio	*49.76*	*2.80*	$5.367x\ 10^{-11}$
Water absorption	*5091*	*3.48*	$1.71x10^{-16}$
Compressive strength	*87.82*	*2.80*	$1.38x10^{-13}$
Flexural strength	*8.73*	*3.48*	$2.67x10^{-13}$
Durability	*2.37*	*2.21*	$3.62x10^{-2}$

3.1 Consistency

As shown in (Figure 4), the percentage increase of PCA replacing NCA directly influenced the reduction of concrete consistency in its fresh state.

Data showed a significant difference between the means (Table 4). With the Tukey test, it was verified that this difference was more significant in relation to the reference sample, reaching a reduction of up to 16.18% to 40% of incorporation of polymeric aggregate, not showing relevant variations between the formulations with the polymeric residue of polyurethane. Algahtani, (2022) and Rukavina et al., (2021) in their research, obtained similar results and observed that the variation in this property is due to the use of additives that manage to maintain a controlled consistency variation compared to the reference sample.

Bamigboye et al., (2021), who incorporated polyethylene terephthalate (PET) polymeric aggregate in the production of lightweight concrete, observed a reduction in consistency with the increase in polymer incorporation by up to 40%. After this value, the consistency increased, and this

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is attributed to the increase of water absorption by polymeric aggregates at low rates. According to Coppola et al., (2016), this behavior occurs due to the non-uniform shape of the polymeric grains and their hydrophobic nature, which promote difficulty in the cohesion between the particles of the mixture. In general, polymers have low or no water absorption, which makes it difficult to bond with cement.

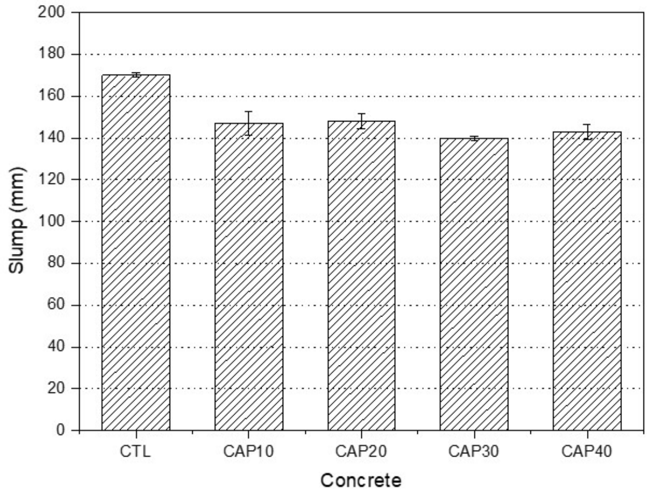

Figure 4. Slump results of the produced concrete.

According to Steyn et al., (2021), this behavior is due to the polymeric grains having a lower specific mass and a rougher surface with more irregular edges, which cause an increase in air bubbles on the polymeric surface, being incorporated into the concrete. According to similar research by Jacob-Vaillancourt and Sorelli, (2018) and according to Neville, (2015), the water/cement ratio directly influences the voids in concrete. Therefore, it is suggested to analyze tests with variations of this w/c ratio and the behavior of concrete with polymeric aggregate.

3.2 Specific gravity

As shown in (Figure 5), the decrease in the actual density is positively correlated with the increase in PCA incorporation in the concrete. The results showed that there is a difference between the means (Table 4); with the Tukey test, it was verified that a variation of the reference sample compared to the formulations with 20%, 30%, and 40% of polymeric aggregate incorporation, reduced the specific gravity of the concrete between 2.67% and 8.71 %. However, for the incorporation of 10% of the residue, it was observed that there was no significant variation in relation to the reference sample. Thus, the PCA shows a greater decrease in this property with more than 10% of incorporation in the samples.

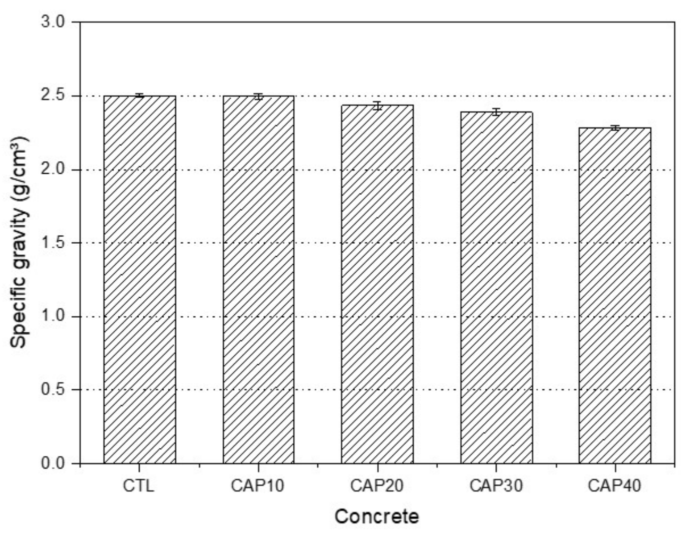

Figure 5. The specific gravity of the produced concretes.

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Likewise, these values are consistent with the results of Kangavar et al., (2022), Hameed and Ahmed, (2019) who observed a reduction in the specific gravity of concrete with the incorporation of polymeric aggregate by up to 12% for a replacement of up to 30% of NCA by PCA. The behavior of concrete with PCA can be explained by the reduced density of polymeric grains compared to NCA.

3.3 Void ratio

From the analysis of (Figure 6), the values found in the void ratio test showed that there is a significant difference between the means (Table 4); with the Tukey test, it was verified when substituting NCA for PCA, there was a gradual increase in the void ratio up to 31.44% in the concrete.

According to (Colangelo et al., 2016), this behavior is due to the weakening of the Interfacial Transition Zone (ITZ), which represents a small region close to the coarse aggregate particles and the cement paste. Therefore, the more porous ITZ contributes to a more porous matrix and significant voids (Silva et al., 2020).

This analysis is consistent with the results of Coppola et al., (2016). In these studies, it was observed that from the 10% incorporation of polymeric residues in the mixture, an increase of up to 15% in the void ratio was noticed, compared with the reference sample.

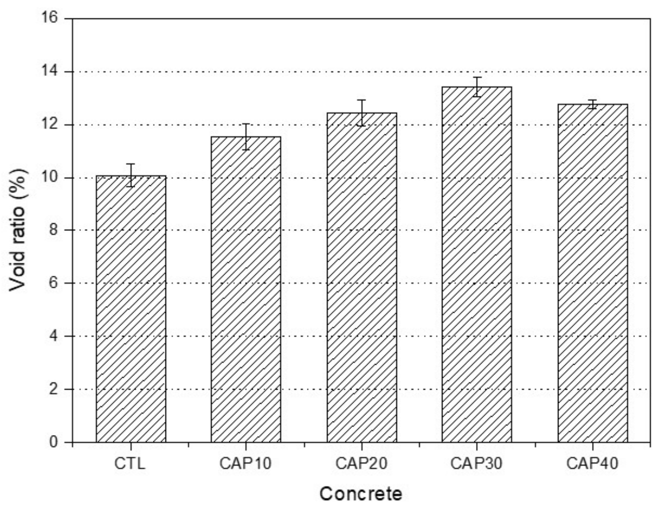

Figure 6. Void ratio of the produced concretes.

3.4 Water absorption

It is noted in (Figure 7), that there was an increase in water absorption in the samples with PCA compared to the reference samples. The results obtained showed that there is a significant difference between the averages (Table 4); with the Tukey test, it was analyzed that all formulations showed a significant increase when compared to the sample without PCA. There is a significant increase in water absorption of approximately 47.13% compared to the reference sample. Like the void ratio, this behavior is justified by the fact that there is no strong connection in the Interfacial Transition Zone, which consequently allows more pores to be filled with water, determining a direct connection between the increase in void ratio with the addition of water absorption of formulations containing PCA (Ferreira et al., 2012).

Similar results are presented by Abu-Saleem et al., (2021) and Colangelo et al., (2016) who investigated variations of up to 50% in the incorporation of recycled aggregate in the mixture and observed an increase of up to 100% in the percentage of water absorption in concrete with this aggregate, when compared to the reference sample. This can also be attributed to the increase in the mixture's void content during the fresh state, promoting greater spaces between the grains and thus, and also greater absorption of water by the cementitious matrix.

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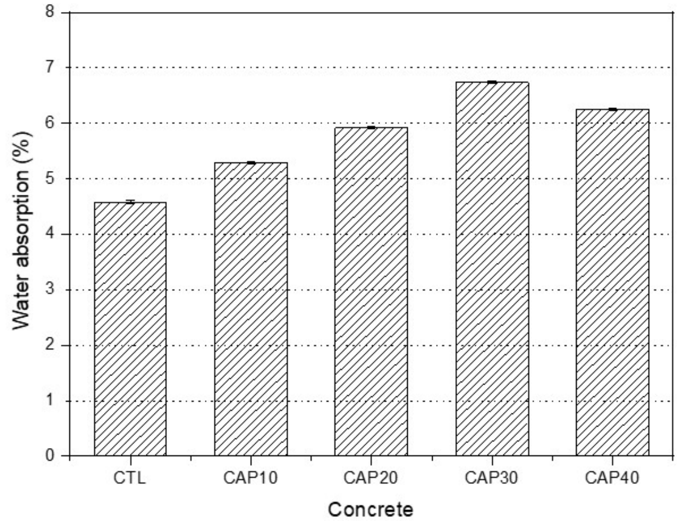

Figure 7. Water absorption of the produced concretes.

3.5 Compressive strength

(Figure 8) shows the values found in the compressive strength test, carried out at 28 days of age. The results showed that there are significant differences between the averages (Table 4) and with the Tukey test it was analyzed that the replacement of the NCA by PCA, in percentages from 10% to 40%, resulted in significant losses of 34.60% to 81.40% of the compressive strength, in comparison with the reference concrete. Other authors used NCA, replacing between 5% and 100% with PCA, and found lower results than the reference sample (Gonzalez-Corominas and Etxeberria, 2016).

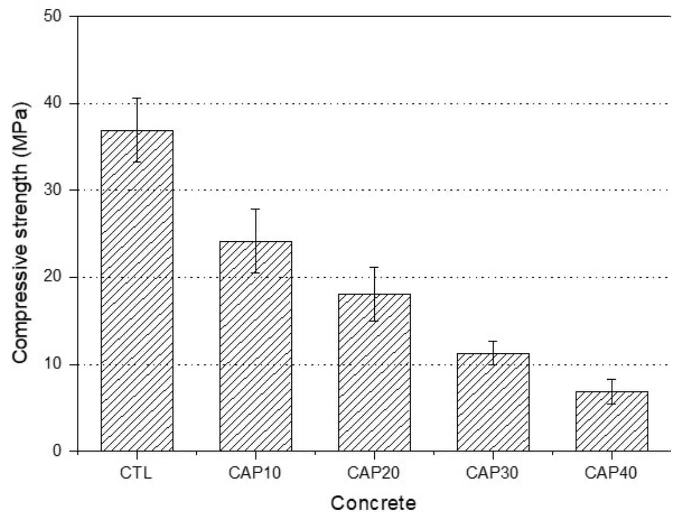

Figure 8. Compressive strength of the produced concretes.

It is possible to affirm that the increase of the polymeric content, in substitution of the NCA, tends to reduce the compressive strength of the concretes. This is due to the non-uniform shape of the polymeric particles and, consequently, compromises the friction in the interfacial transition zone, which is weaker and nullifies the force redistribution effect, which reduces the compressive strength (Steyn et al., 2021).

The reduction in compressive strength for higher levels of substitution of NCA by PCA has already been justified by other researchers (Olofinnade et al., 2021), a fact that can be attributed to the lower mechanical strength of the polymers, when compared to the granitic rock aggregate.

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However, with an ideal percentage of 10% of polymeric aggregate, combined with the addition of air-entraining and studies of different water/cement ratios, those facts can provide an improvement in the compressive strength of samples with PCA (Mohammadinia et al., 2019).

Pinheiro and Crivelaro, (2020) recorded that adding polymeric residues at 5%, to replace the natural aggregate and incorporating additives that reduce the air content in these samples, produced compressive strength results, similar to the reference samples. Therefore, the air content is directly linked to the compressive strength values, but in the present study, no additives were used that allowed this reduction of the air content in the materials produced.

3.6 Flexural strength

(Figure 9) shows the results of flexural strength at 28 days of age. The data showed that there are significant differences between the averages (Table 4) and with the Tukey test it was analyzed that there was a reduction in values of the flexural strength of the samples with PCA compared to the control sample (CLT). Authors such as Pongsopha et al., (2022) used up to 20% substitution of natural aggregate for polymeric aggregate in the concrete composition and found similar results for flexural strength.

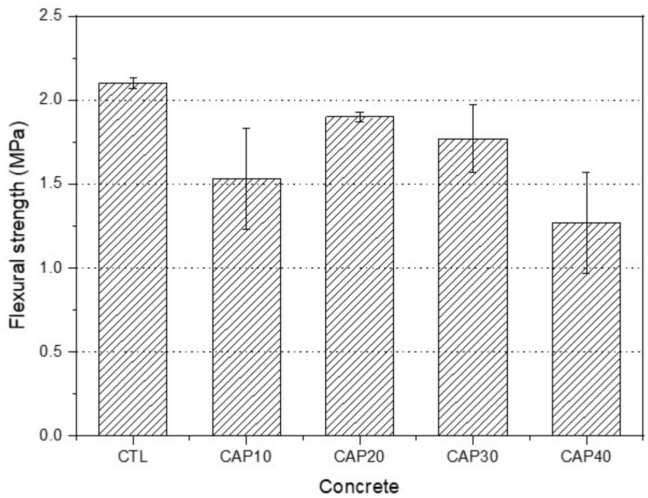

Figure 9. Flexural of the produced concretes.

It is possible to affirm that the increase of the polymeric content, in substitution of the NCA, tends to reduce the flexural strength of the concretes. This behavior is justified by the formation of voids, caused by the rough and irregular surface of the recycled aggregate, as well as the formation of voids within the concrete, with the low bond between the polymer particles and the cement paste. For samples with up to 20% polymeric aggregate incorporation, there is a minimal variation in flexural strength. However, for percentages greater than 50% of polymeric aggregates, there is a reduction greater than 30% of this property (Faraj et al., 2019).

Despite this reduction in flexural strength with the incorporation of PCA, it was observed that the samples did not undergo the same process of abrupt rupture as the control sample (CLT). Additionally, the polymeric aggregates helped in the greater flexibility of the concrete samples before their rupture, when the force of flexion is applied. According to Olofinnade et al., (2021), this is attributed to the elastic nature and the non-brittle characteristic of the polymeric aggregate under load, so that the cracks produced before rupture, contour the polymer particles to be propagated in the matrix and retard the fracture phase. Hence, it should be analyzed that despite the reduction in the flexural strength values of concrete with PCA, this aggregate can be used as a way of delaying the action of the flexural force on the cementitious matrix, promoting an increase in the useful life of the cement matrix construction.

3.7 Durability

(Table 5) presents the values found in the durability test of the samples exposed to sodium sulfate solution (Na_2SO_4), where the variation in the percentage of mass gain/loss was evaluated. The results showed that there is a significant difference between the average mass loss of the

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samples with PCA and with only NCA, and it was verified that with the increase of the PCA, there is a reduction of the mass loss in the concrete, being the percentage of 40% of PCA with less mass loss, after 84 days of exposure to acidic solution.

This reduction in mass loss as PCA is incorporated into the concrete, is due to the microstructure of the polymeric aggregate in the cementitious matrix, having the ability to react with the acidic solution surrounding the concrete, increasing the surrounding hydrogen ion potential (pH), and making the solution less aggressive to concrete, as well improving its resistance to acid attack (Wongkvanklom et al., 2021).

The samples also showed an apparent change in surface wear, verified by the formation of sediments in the solution and the loss of mass of the samples after 28 days. Likewise, a greater wear of the edges and ends on the surface of the concrete was observed, mainly in the reference sample. These factors indicate that the polymeric aggregate replacing the conventional coarse aggregate could increase the resistance of the concrete to the attack of aggressive agents and decrease its deterioration in surface levels.

Table 5. Weight gain/loss of samples.

Days	*Weight gain/loss of samples of exposure to sodium sulfate solution (%)*									
	CLT	σ	***CAP10***	σ	***CAP20***	σ	***CAP30***	σ	***CAP40***	σ
7	↑0.06	0.04	↓0.02	0.04	↑0.05	0.01	↑0.05	0.07	0	-
14	↑0.21	0.09	↑0.13	0	↑0.14	0.01	↑0.16	0.1	↑0.36	0.04
28	↑0.23	0.07	↑0.22	0.03	↑0.23	0.02	↑0.21	0.05	↑0.65	0.04
56	↓0.66	0.09	↓0.54	0.06	↓0.59	0.04	↓0.51	0.03	↓0.39	0.01
84	↓1.17	0.04	↓0.94	0.16	↓1.11	0.10	↓0.84	0.02	↓0.10	0.01

This behavior is confirmed by Sá Ribeiro et al., (2021), Surendar et al., (2021), and Dulsang et al., (2016) who justified it by the fact that these polymeric materials have a lower porosity compared to natural aggregates, making it difficult for the diffusion of chemical agents in concrete. Given this, it was evaluated that polymeric materials can help satisfactorily in the prevention of chemical reactions between the aggressive factors and the concrete.

(Figure 10) shows the results of the compressive strength of the samples before and after 84 days in an aggressive solution. It is noticed that there are significant differences for the samples (Table 4) and by Tukey's test it was verified a reduction of the values of the compressive strength of the concretes with polymeric glue in relation to the control sample (CLT). This reduction of the compressive strength in CLT (44%), CAP10 (46%), and CAP20 (47%) is shown in comparison with the samples that were not exposed to sodium sulfate solution. This reduction in compressive strength with exposure time is already expected by authors (Sá Ribeiro et al., 2021), (Qu et al., 2021), (Dulsang et al., 2016). Those behaviors are justified by the increase in the voids index and porosity as revealed by the SEM in (Figure 11), which contains a direct relationship with compressive strength performance.

Nevertheless, for the composites CAP30 and CAP40, there were no significant differences in the compressive strength after 84 days of immersion, even with the increase of void index and weakening of the transition zone. This stagnation can be attributed to the addition of polymeric aggregate, which contains a rougher surface and less water absorption, which produces a reduction in the penetration of acid inside the cementitious matrix, making it resistant to sodium sulfate attack, as revealed by some researchers (Surendar et al., 2021), (Huang et al., 2021), (Kazmi et al., 2020). Considering that the reference values obtained strength compressive, a greater loss of mass and visual aspects such as discolouration and surface wear compared to concrete with PCA, it is possible to state that the formulations with PCA met improved durability.

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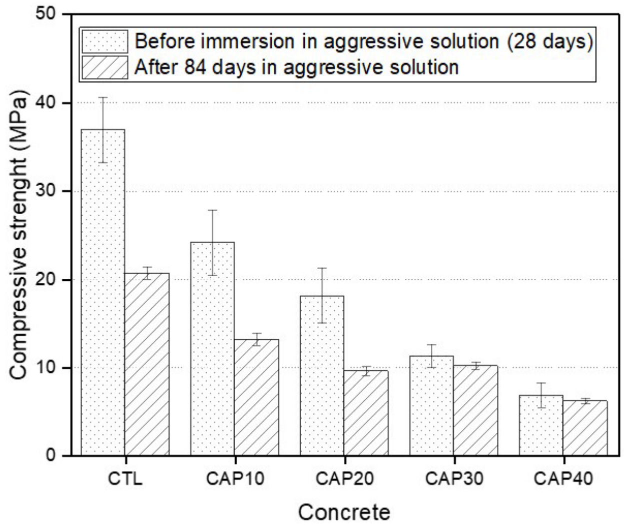

Figure 10. Compressive strength of samples after durability test.

3.7.1 Microstructure Analysis

In (Figure 11), the Scanning Electron Microscopy (SEM) analyzes are presented for the CAP40 concrete, which obtained the best result during the test in an aggressive medium. In general, it is possible to identify the presence of some of the main components of the hydrated cement paste: interfacial transition zone, voids, pores, fissures, and aggregate phase for both polymer and conventional formulations.

The polymeric residue can be identified as an uneven surface phase with slight roughness. Due to the scale and magnification used, it is possible to have a broad view of the ITZ. The void space in the centre of the ITZ represents the lack of adherence to the polymeric aggregate and the cement paste. It is still possible to analyze its topographies, which are quite irregular, with several regions of voids and fissures. Another important point to be highlighted is the poor adhesion between the cement paste and the polymer, evidenced by the void along the ITZ, as well as the appearance of cracks along the cement paste. These facts and the presence of voids together with the lack of adhesion add up and contribute significantly to the loss of mechanical strength of concrete.

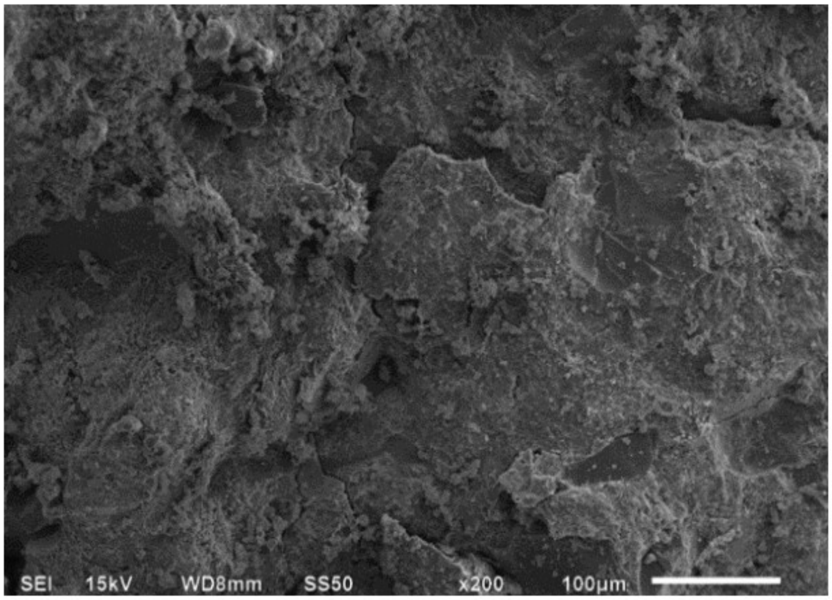

Figure 11. Scanning Electron Microscopy of concrete with polymeric aggregate.

In general, in the SEM test, it was observed in the topographies that the ITZ between polymeric aggregate and cement paste was compromised since it does not present a consistent connection. This fact can be attributed to the hydrophobic nature of the polymer, which has a surface that

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does not fully adhere to ceramic materials such as Portland cement (Colom et al., 2013). Materials of polymeric origin do not have an adherent surface, as in conventional aggregates (limestone, granite, sandstone, quartz). If there is no deposit of a thin layer of water and cement paste on the aggregates, this compromises the ITZ, weakening the concrete with polymeric residues as a whole (Thomas and Gupta 2016).

Despite this fragility of the ITZ, it is noted that the CAP40 composite obtained a satisfactory result for durability with less wear on the surface and discoloration of the samples. The justification for such behavior relies on the fact that these polymeric materials have a hydrophobic surface and less porosity compared to natural aggregates, hindering the diffusion of chemical agents (Dulsang et al., 2016), (Sá Ribeiro et al., 2021), (Surendar et al., 2021).

4. Conclusion

The objective of this research was to produce some concrete with recycled aggregate of polymeric glue, replacing NCA, to analyze the physical-mechanical properties and durability. During the tests, the importance that should be given to the air content of the mixture was observed, as it has an intense influence on the void ratio, water absorption, and consequently, the compressive strength of the concrete. Regarding specific mass, note that there is a gradual reduction in this property as the percentage of PCA in the increased concrete, indicating that the polymeric residue has a lighter density than the conventional one.

For the void ratio and water absorption, a gradual increase in these properties was obtained, as the polymeric aggregate was incorporated into the mixture. This result makes it possible to associate this analysis with the decrease in the compressive strength of the samples since they are important parameters in the performance of the mechanical properties. In terms of compressive strength, the partial replacement of NCA by PCA results in a reduction in the strength of the produced concretes. However, despite this reduction, the samples with up to 10% of NCA met the minimum standards for structural works in the minimum value of 20 MPa for compressive strength.

As for flexural strength, it was observed that the samples containing PCA did not show abrupt ruptures like those with NCA, which indicates improvements to foundations and maintenance of buildings, ensuring an advantage over conventional concrete and its behavior for flexural strength. As for durability, all formulations with PCA showed lower values of mass loss compared to the reference sample. The best combination was for 40% incorporation of PCA when replacing it with NCA. The polymeric coarse aggregate showed positive results regarding the durability of concrete.

The feasibility of using this type of waste in partial replacement of the natural coarse aggregate in the production of concrete, proved itself to be an alternative with socioeconomic benefits concerning a more sustainable purpose of industrial waste, which would lead to a reduction in expenses with these disposals, a decrease in the extraction of large amounts of raw materials and a reduction in the pollution of these materials in the environment. In addition, some non-structural applications can be made with this type of polymeric aggregate, such as a lighter concrete precast, which would reduce the final costs of the building. Another possible application is found in the construction of factories, industrial floors, and other environments that suffer from aggressive agents, due to its action to reduce the attack of acid on concrete, reducing costs with maintenance and repairs of these structures.

Therefore, in this study, it was possible to produce concrete with the incorporation of coarse aggregate from polymeric glue residue, which represents an alternative to produce a more sustainable concrete.

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6. References

Abu-Saleem, M.; Zhuge, Y.; Hassanli, R.; Ellis, M.; Rahman, M.; Levett, P. (2021). Evaluation of concrete performance with different types of recycled plastic waste for kerb application. Constr. Build. Mater., 293, 123477. https://doi.org/10.1016/j.conbuildmat.2021.123477.

Algahtani, F. K. (2022). Assessment of fresh and mechanical characteristics of lightweight concrete containing manufactured plastic aggregates. Jour. Build. Eng., 148, 104169. https://doi.org/10.1016/j.jobe.2022.104169.

Al-Mansour, A.; Chen, S.; Xu, C.; Peng, Y.; Wang, J.; Ruan, S.; Zeng, Q. (2022). Sustainable cement mortar with recycled plastics enabled by the matrix-aggregate compatibility improvement. Constr. Build. Mater., 318, 1-6. https://doi.org/10.1016/j.conbuildmat.2021.125994.

ASTM C267 – 20 (2020). Standard Test Methods for Chemical Resistance of Mortars, Grouts, and Monolithic Surfacings and Polymer Concretes. United States.

Bamigboye, G. O.; Tarverdi, K.; Umoren, A.; Bassey, D. E.; Okorie, U.; Adediran, J. (2021). Evaluation of eco-friendly concrete having waste PET as fine aggregates. Cleaz. Mater., 2, e100026. https://doi.org/10.1016/j.clema.2021.100026.

Basha, S. I.; Ali, M. R.; Al-Dulaijan, S. U.; Maslehuddin, M. (2020). Mechanical and thermal properties of lightweight recycled plastic aggregate concrete. Jour. Build. Eng., 32, e101710. https://doi.org/10.1016/j.jobe.2020.101710.

Brazilian Association of Standards Techniques (2018). ABNT NBR 5739: Concrete – Compression test of cylindrical specimens. Brazil.

Brazilian Association of Standards Techniques (2022). ABNT NBR 7211: Aggregates for concrete – Requirements. Brazil.

Brazilian Association of Standards Techniques (2009). ABNT NBR 9778: Hardened mortar and concrete – Determination of absorption, voids and specific gravity. Brazil.

Brazilian Association of Standards Techniques (2009). ABNT NBR 9833: Fresh concrete – Determination of the unit weight, yield and air content by the gravimetric test method. Brazil.

Brazilian Association of Standards Techniques (2010). ABNT NBR 12142: Concrete – Determination of tension strength in flexure of prismatic specimens. Brazil.

Brazilian Association of Standards Techniques (2014). ABNT NBR 13583: Portland cement – Determination of volumetric change of Portland cement mortar bars exposed to sodium sulphate solution. Brazil.

Brazilian Association of Standards Techniques (2018). ABNT NBR 16697: Portland cement – Requirements. Brazil.

Brazilian Association of Standards Techniques (2020). ABNT NBR 16889: Fresh concrete – Slump test. Brazil.

Colangelo, F.; Cioffi, R.; Liguori, B.; Lucolano, F. (2016). Recycled polyolefins waste as aggregates for lightweight concrete. Comp. Part. B: Engin., 106, 234-241. https://doi.org/10.1016/j.compositesb.2016.09.041.

Colom, X.; Cañavate, J.; Carrillo, F.; Lis, M. (2013). Acoustic and mechanical properties of recycled polyvinyl chloride/ground tyre rubber composites. Journ. Comp. Mater., 48 (9), 1061-1069. https://doi.org/10.1177/0021998313482154.

Coppola, B.; Courard, L.; Michel, F.; Incarnato, L.; Maio, L. D. (2016). Investigation on the use of foamed plastic waste as natural aggregates replacement in lightweight mortar. Comp. Part. B: Eng., 99, 75-83. https://doi.org/10.1016/j.compositesb.2016.05.058.

Dulsang, N.; Kasemsiri, P.; Posi, P.; Hiziroglu, S.; Chindaprasirt, P. (2016). Characterization of an environment friendly lightweight concrete containing ethyl vinyl acetate waste. Mat. Desig., 96, 350-356. https://doi.org/10.1016/j.matdes.2016.02.037.

Faraj, R. H.; Sherwani, A. F. H.; Daraei, A. (2019). Mechanical, fracture and durability properties of self-compacting high strength concrete containing recycled polypropylene plastic particles. Jour. Build. Eng., 25, 100808. https://doi.org/10.1016/j.jobe.2019.100808.

ISSN: 0718-5073

Vol. 40
Nº1 2025
DOI: 10.7764/RIC.00142.21

Ferreira, L.; Brito, J.; Sikia, N. (2012). Influence of curing conditions on the mechanical performance of concrete containing recycled plastic aggregate. Constr. Build. Mater., 36, 196-204. https://doi.org/10.1016/j.conbuildmat.2012.02.098.

Gama, N.; Godinho, B.; Marques, G.; Silva, R.; Barros-Timmons, A.; Ferreira, A. J. C. E. J. (2020). Recycling of polyurethane scraps via acidolysis. Chem. Eng. J., 395, 125102. https://doi.org/10.1016/j.cej.2020.125102.

Gharib, J.; Pang, S.; Holland, D. (2020). Synthesis and characterisation of polyurethane made from pyrolysis bio-oil of pine wood. Eur. Polym. J., v. 133, p. 109725. http://dx.doi.org/10.1016/j.eurpolymj.2020.109725.

Gonzalez-Corominas, A.; Etxeberria, M. (2016). Effects of using recycled concrete aggregates on the shrinkage of high performance concrete. Constr. Build. Mater., 115, 32-41. https://doi.org/10.1016/j.conbuildmat.2016.04.031.

Hameed, A. M.; Ahmed, B. A. F. (2019). Employment the plastic waste to produce the light weight concrete. Technologies and Materials for Renewable Energy. Environ. Sustain., 157, 30-38, https://doi.org/10.1016/j.egypro.2018.11.160.

Huang, J.; Zou, C.; Sun, D.; Yang, B.; Yan, J. (2021). Effect of recycled fine aggregates on alkali-activated slag concrete properties. Structur., 30, 89-99. https://doi.org/10.1016/j.istruc.2020.12.064.

Jacob-Vaillancourt, C.; Sorelli, L. (2018). Characterization of concrete composites with recycled plastic aggregates from postconsumer material streams. Constr. Build. Mater., 182, 561-572. https://doi.org/10.1016/j.conbuildmat.2018.06.083.

Kangavar, M. E.; Lokuge, W.; Manalo, A.; Karunasena, W.; Frigione, M. (2022). Investigation on the properties of concrete with recycled polyethylene terephthalate (PET) granules as fine aggregate replacement. Cas. Stud. Constr. Mater., 16, 00934. https://doi.org/10.1016/j.cscm.2022.e00934.

Kazmi, S. M. S.; Munir, M. J.; Wu, Y.; Patnaikuni, I.; Zhou, Y.; Xing, F. (2020). Effect of recycled aggregate treatment techniques on the durability of concrete: A comparative evaluation. Constr. Build. Mater., 264, 120284. https://doi.org/10.1016/j.conbuildmat.2020.120284.

Mohammadinia, A.; Wong, Y. C.; Arulrajah, A.; Horpibulsuk, S. (2019). Strength evaluation of utilizing recycled plastic waste and recycled crushed glass in concrete footpaths. Constr. Build. Mater., 197, 489-496. https://doi.org/10.1016/j.conbuildmat.2018.11.192 .

Neville, A. M. (2015). Concrete Properties. 5. ed. São Paulo: Bookman, 912 p.

Olofinnade, O.; Chandra, S.; Chakraborty, P. (2021). Recycling of high impact polystyrene and low-density polyethylene plastic wastes in lightweight based concrete for sustainable construction. Mater. Today, 38 (5), 2151-2156. https://doi.org/10.1016/j.matpr.2020.05.176.

Pinheiro, A. C. F. B.; Crivelaro, M. (2020). Construction Materials. 3. ed. São Paulo: Érica, 184 p.

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

Qu, F.; Li, W.; Wang, K.; Zhang, S.; Sheng, D. (2021). Performance deterioration of fly ash/slag-based geopolymer composites subjected to coupled cyclic preloading and sulfuric acid attack. Journ. Clean. Produc., 321, 128942. https://doi.org/10.1016/j.jclepro.2021.128942.

Rukavina, J. M.; Baricevic, A.; Serdar, M.; Grubor, M. (2021). Study on the post-fire properties of concrete with recycled tyre Polymer fibres. Cem. Conc. Comp., 123, 104184. https://doi.org/10.1016/j.cemconcomp.2021.104184.

Sá Ribeiro, M. G.; Sá Ribeiro, M. G.; Keane, P. F.; Sardela, M. R.; Kriven, W. M.; Sá Ribeiro, R. A. (2021). Acid resistance of metakaolin-based, bamboo fiber geopolymer composites. Constr. Build. Mater., 302, 124-194. https://doi.org/10.1016/j.conbuildmat.2021.124194.

Sebsadji, S. K. (2022). Determining concrete properties for different optimized combined concrete mixtures: Novel mathematical approach. Powder Technol., 409, 117756. http://dx.doi.org/10.1016/j.powtec.2022.117756.

Silva, L. R. R.; Silva, J. A.; Francisco, M. B.; Ribeiro, V. A.; Souza, M. H. B.; Capellato, P.; Souza, M. A.; Santos, V. C.; Gonçalves, P. C.; Melo, M. L. N. M. (2020). Polymeric Waste from Recycling Refrigerators as an Aggregate for Self-Compacting Concrete. Sustainability, 12(20), 8731. https://doi.org/10.3390/su12208731.

Steyn, Z. C.; Babafemi, A. J.; Fataar, H.; Combrinck, R. (2021). Concrete containing waste recycled glass, plastic and rubber as sand replacement. Constr. Build. Mater., 269, 121242. https://doi.org/10.1016/j.conbuildmat.2020.121242.

Surendar, M.; Ananthi, G. B. G.; Sharaniya, M.; Deepak, M. S.; Soundarya, T. V. (2021). Mechanical properties of concrete with recycled aggregate and M-sand." Mater. Proceed., 44 (1), 1723-1730. https://doi.org/10.1016/j.matpr.2020.11.896.

Thomas, B. S.; Gupta, R. C. (2016). Properties of high strength concrete containing scrap tire rubber. Journ. Clean. Prod., 113, 86-92. https://doi.org/10.1016/j.jclepro.2015.11.019.

Wongkvanklom, A.; Posi, P.; Kampala, A.; Kaewngao, T.; Chindaprasirt, P. (2021). Beneficial utilization of recycled asphaltic concrete aggregate in high calcium fly ash geopolymer concrete. Cas. Stud. Constr. Mater., 15, 00615. https://doi.org/10.1016/j.cscm.2021.e00615.

World Wide Fund for Nature (2019). Brazil is the 4th country in the world that generates the most polymers waste. https://www.wwf.org.br/?70222/Brasil-e-o-4-pais-do-mundo-que-mais-gera-lixo-plastico.

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Nº1 2025
DOI: 10.7764/RIC.00142.21

Záleská, M.; Pavlíková, M.; Pokorný, O.; Pavlík, Z.; Cerný, R. (2018). Structural, mechanical and hygrothermal properties of lightweight. Constr. Build. Mater., 180, 1-11. https://doi.org/10.1016/j.conbuildmat.2018.05.250.

ISSN: 0718-5073