Periódico Eletrônico Fórum Ambiental da Alta Paulista
Electronic Journal Environmental Forum of Alta Paulista
ISSN 2966-2931 Suporte Online / *Online Support* - ISSN 1980-0827 Suporte CD-ROM / *CD-ROM Support*

Edição em Português e Inglês / *Edition in Portuguese and English* - v. 20, n. 2, 2024

Sustainable Cementitious Materials: Applications and Potentialities of PCR-PET

Raul de Souza Brandão
PhD Professor, IFES, Brazil.
PhD Student, UENF, Brazil.
raul.brandao@ifes.edu.br

José Augusto Pedro Lima
PhD Professor, UENF, Brazil.
japlima@uenf.br

Jonas Alexandre
PhD Professor, UENF, Brazil.
jonas@uenf.br

Periódico Eletrônico Fórum Ambiental da Alta Paulista
Electronic Journal Environmental Forum of Alta Paulista
ISSN 2966-2931 Suporte Online / Online Support - ISSN 1980-0827 Suporte CD-ROM / CD-ROM Support
Edição em Português e Inglês / *Edition in Portuguese and English* - v. 20, n. 2, 2024

SUMMARY
This article explores the applicability of Post-Consumer Recycled Polyethylene Terephthalate (PCR-PET) in sustainable cementitious materials, highlighting its relevance to sustainable construction. It discusses the incorporation of recycled PET into a variety of cementitious materials such as mortar, concrete, pavements, blocks, bricks, pipes, artificial rocks, panels, urban furniture, and tiles, demonstrating the environmental and technical benefits of these materials. Additionally, it presents case studies and experimental results illustrating the effective application of PCR-PET in these areas. These studies reveal, in some cases, the positive influence of adding recycled PET on the properties of materials, from mechanical strengt and durability to thermal and acoustic performance of applications. Finally, it emphasizes the role of PCR-PET in reducing plastic waste, promoting circular economy, and contributing to sustainability in the construction industry. In summary, this article underscores the potential use of PCR-PET as an essential tool for advancing sustainable construction, providing innovative and responsible solutions to the environmental challenges faced by the construction materials industry.

KEYWORDS: PCR-PET. Sustainability. Building Materials.

1 INTRODUÇÃO

The construction materials industry plays a crucial role in economic development and global infrastructure; however, historically, it has been one of the largest consumers of natural resources and generators of waste (MASUERO, 2021).

In light of the environmental and social challenges faced by the planet, the pursuit of more sustainable practices has become an undeniable priority across all sectors, including, of course, the construction industry. Therefore, it is essential to highlight the specific challenges that the construction industry faces, such as the high demand for resources and massive waste generation, to better contextualize the need for sustainable solutions.

Sustainability in the construction materials industry refers to the search for methods, materials, and processes that minimize environmental impact, promote energy efficiency, reduce waste production (MASUERO, 2021), and improve the quality of life for local communities. This approach not only meets the needs of the present but also protects resources for future generations.

One of the main challenges faced in this journey towards sustainability is the need to develop and implement effective and sustainable analysis methods to assess the quality and performance of construction materials. Material analysis plays a fundamental role in all stages of a construction project's life cycle, from material selection to the evaluation of various properties such as durability and structural performance.

However, many traditional methods of applying inputs used in the construction materials industry can be costly, time-consuming, and result in significant waste. Additionally, some analysis methods may not be sensitive enough to detect impurities or additives at low concentrations, which can compromise the quality and safety of construction materials.

Therefore, there is an urgent need to develop and adopt more effective and sustainable analysis methods that can provide accurate and reliable information on the composition, properties, and performance of construction materials (PASSUELLO et al., 2014), while minimizing environmental impact, associated costs, and providing relevant information for safety in applications.

In this context, the application of Post-Consumer Recycled Polyethylene Terephthalate (PCR-PET) in sustainable cementitious materials emerges as a promising approach to meet the demand for sustainable cementitious materials. PCR-PET offers the ability to perform rapid, sensitive, and quantitative analyses, promoting a reduction in reagent consumption and waste generation, making it an attractive tool for the construction materials industry, which is increasingly focused on meeting sustainable needs.

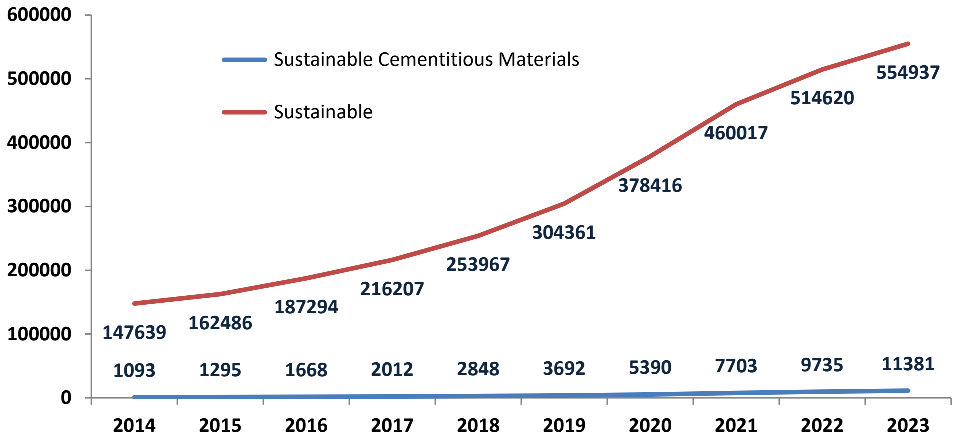
By analyzing the applicability of PCR-PET in cementitious materials in a sustainable manner, this article seeks to contribute to the advancement of research and practical application in the field of sustainable construction, providing information on innovative techniques that can be employed in various projects around the world, with the aim of generating improvements in the quality, efficiency, and environmental sustainability of materials applied in the development of modern built environments.

2 POTENTIAL APPLICATIONS OF SUSTAINABLE CEMENTITIOUS MATERIALS WITH PCR-PET

Sustainable cementitious materials represent a significant evolution in the construction industry, aiming to reduce environmental impact and promote more responsible practices throughout the material life cycle. These materials are developed with the goal of minimizing natural resource consumption, reducing carbon emissions, and improving energy efficiency without compromising the quality and performance of constructed structures (PASSUELLO *et al.,* 2014).

In Figure 1, a graph from research conducted on the Dimensions platform is presented, showing the number of articles published over a 10-year period, from 2014 to 2023. This research covers the topics of "Sustainable" and "Sustainable Cementitious Materials."

Figure 1 – Number of articles published on the topics: Sustainable Cementitious Materials and Sustainability



Source: AUTHORS, 2024.

Upon further analysis of Figure 1, there is a noticeable and steady increase in interest in the topics of Sustainable Cementitious Materials and Sustainability throughout the period examined. A nearly constant growth is observed in the subtopic of Sustainable Cementitious Materials, within the broader context of sustainability.

With the growing interest in developing new materials with a sustainable footprint, some potential applications for the study and development of sustainable cementitious materials incorporating PCR-PET into their compositions are highlighted below.

2.1 Mortars

Mortars are binding materials used in construction for laying bricks, blocks, wall plastering, and flooring. The use of recycled PET in mortar composition can offer several benefits, such as reducing sand consumption, improving mechanical and thermal properties, and decreasing the weight of structures. PCR-PET can be incorporated as a partial substitute for sand in mortar mixtures, providing a sustainable and economically viable alternative for the production of construction materials.

2.2 Concrete

In concrete, the use of recycled PET is an innovative way to repurpose plastic waste, especially PET bottles, in the production of sustainable construction materials. In this process, recycled PET is shredded and added as a partial replacement for conventional aggregates like sand and crushed stone in the mix. Concrete with PCR-PET can exhibit satisfactory mechanical properties, provided the dosage process is carefully controlled, and it has the potential to be used in various construction applications, thus contributing to the sustainability of the construction industry.

2.3 Permeable Pavements

Permeable pavements are a sustainable alternative to conventional pavements, as they allow water infiltration into the soil, helping to recharge groundwater and reducing stormwater runoff. In the production of permeable pavements, recycled PET can be used as part of the aggregate mix, providing a permeable and durable surface. The incorporation of PCR-PET not only reduces natural resource consumption but also contributes to sustainable stormwater management and flood prevention in urban areas.

2.4 Blocks and Bricks

Another interesting application of recycled PET in the construction materials industry is the production of blocks and bricks using PCR-PET as part of the composition. In this case, recycled PET is ground into small pieces and mixed with cement, sand, water, and other additives to form a homogeneous mixture. This mixture is then molded into blocks and bricks, which can be used in walls, fences, and other masonry structures. The incorporation of PCR-PET into blocks and bricks not only reduces the consumption of natural resources but also offers additional benefits such as thermal and acoustic insulation, lightness, and ease of handling during construction. These blocks and bricks with PCR-PET are a sustainable alternative to conventional ones and help reduce the environmental impact of the construction industry.

2.5 Roof Tiles and Covering Elements

Roof tiles and covering elements are essential components in the construction of roofs and building covers. Incorporating PCR-PET into the production of roof tiles and covering elements can offer a sustainable alternative to conventional materials like ceramic and fiber cement. PCR-PET can be used as part of the tile composition, offering benefits such as reduced natural resource consumption, lighter structures, better thermal and acoustic insulation, and greater resistance to impacts and weathering. These roof tiles and covering elements using recycled PET are an eco-friendly option for sustainable building construction.

2.6 Interlocking Pavements

Interlocking pavements are widely used in urban areas for sidewalks, plazas, parking lots, and other light-to-medium traffic surfaces. These pavements consist of prefabricated blocks that fit together, creating a durable and resistant surface.

The incorporation of recycled PET in the production of interlocking blocks offers several advantages, including reduced consumption of natural aggregates, lighter pieces, improved drainage properties, and contributions to the sustainable management of plastic waste

2.7 Drainage Pipes

Drainage pipes are used in various civil construction applications, including rainwater drainage, sewage, and underground drainage systems. A sustainable option for manufacturing these pipes is incorporating recycled PET into their composition.

PCR-PET can be used as one of the components in the material mix for pipe production, providing an eco-friendly alternative for plastic waste management. Drainage pipes made with PET maintain the necessary properties to ensure efficient and durable drainage while contributing to reducing the environmental impact of the construction industry.

2.8 Thermal Insulation Panels

Thermal insulation panels are essential for improving the energy efficiency of buildings, reducing heat loss in winter and heat gain in summer. A sustainable way to manufacture these panels is by incorporating PET-PCR into their composition. Recycled PET can be transformed into fibers or granules and mixed with other insulating materials, such as expanded polystyrene (EPS) or rock wool, to form thermal insulation panels. These panels offer excellent thermal performance, reducing the energy consumption needed to maintain thermal comfort in buildings.

2.9 Urban Furniture Elements

Urban furniture elements, such as benches, trash cans, and tactile paving, play an important role in creating functional and aesthetically pleasing public spaces. A sustainable option for manufacturing these elements is to use recycled PET in their composition. PCR-PET can be molded into different shapes and combined with other materials like metal or wood to create durable and resistant urban furniture elements.

In addition to reducing the consumption of natural resources, using recycled PET provides greater resistance to weathering and wear, extending the life of urban furniture and contributing to more sustainable public spaces.

2.10 Hollow Blocks

Hollow blocks are commonly used in the construction of partition walls, allowing the passage of air and light through the hollow spaces. A sustainable option is the production of these blocks using PCR-PET in their composition. Recycled PET can be combined with other materials, such as cement, sand, and water, to form the blocks. In addition to reducing natural resource consumption, the incorporation of recycled PET increases the lightness of the blocks, facilitating handling and transport during construction.

2.11 Artificial Stones

Artificial stones can be produced to mimic the appearance and texture of natural stones, such as marble, granite, or slate. These materials are often used for facade cladding in commercial and residential buildings. The production of artificial stones is widely employed in civil construction for facade cladding and interior decoration and is increasingly aligned with sustainability principles.

PCR-PET in artificial stones demonstrates the effectiveness of incorporating recycled material. By implementing PCR-PET in production, manufacturers of artificial stones can ensure not only compliance with environmental and safety regulations but also the reliability of their products.

3 MANUFACTURING OF PCR-PET AS RAW MATERIAL

In Figure 2, the manufacturing process of a material known as micronized PCR-PET, often referred to in the literature as PCR-PET sand, is illustrated. It details the steps involved, from the initial collection on streets and selective collection sites to the final bagging and shipping for application.

These stages are:

Initial Collection: The material is collected from streets and selective collection points, where it is separated from common solid waste.

Recycling Plant: The material is then sent to a recycling plant, where it undergoes specific processes for its transformation.

Periódico Eletrônico Fórum Ambiental da Alta Paulista
Electronic Journal Environmental Forum of Alta Paulista
ISSN 2966-2931 Suporte Online / Online Support - ISSN 1980-0827 Suporte CD-ROM / CD-ROM Support
Edição em Português e Inglês / *Edition in Portuguese and English* - v. 20, n. 2, 2024

Cleaning and Disinfection: At the recycling plant, the material goes through cleaning and disinfection stages to remove dirt, organic waste, and any contaminants.

Crushing and Grinding: After cleaning, the material is crushed and ground into small pieces, increasing its malleability and facilitating subsequent processes.

Removal of Metallic Impurities: Next, processes are conducted to remove any metallic impurities present in the recycled material.

Micronization: The material undergoes a micronization process, which reduces it to extremely small particles, achieving the desired granulometry for its specific application.

Bagging and Shipping: Finally, the micronized material is bagged and prepared for shipping to its final destination, where it will be applied in various industries, such as construction and automotive sectors.

Figure 2 – Illustration of PET Sand Manufacturing Process

Source: AUTHORS, 2023.

4 CASE STUDIES OF SUSTAINABLE CEMENTITIOUS MATERIALS WITH PCR-PET

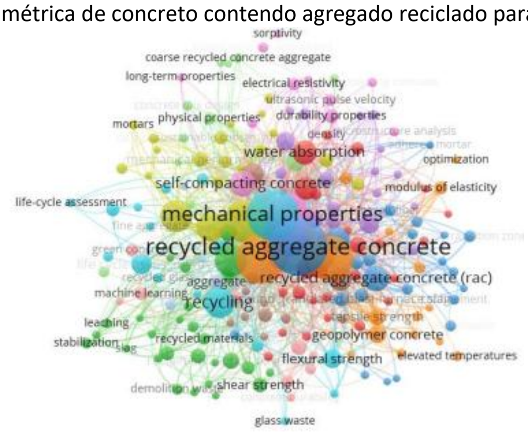
This section explores case studies and experimental results illustrating the effective application of PCR-PET in sustainable cementitious materials.

A study conducted by Marvila *et al.* (2022) evaluated the effects of incorporating PET-PCR in sustainable concretes, aiming to reduce the consumption of natural aggregates, promote plastic waste recycling, and maintain adequate application properties. The analysis demonstrated a direct correlation between the percentage of PET-PCR and the mechanical and physical properties of the concrete, providing valuable insights for the development of new cementitious materials.

Figure 3 presents a bibliometric analysis by Marvila *et al.* (2022) of concrete containing recycled aggregate between 2013-2022. This analysis shows that common construction materials, such as concrete, mortar, geopolymers, and asphalt materials, were frequently studied. The properties examined included mechanical strength, water absorption, elasticity modulus, physical properties, electrical resistivity, sorptivity, ultrasonic pulse velocity, flexural strength, durability, and similar tests. The use of recycled concrete aggregates, construction and demolition waste, glass waste, and slag waste were prevalent.

Periódico Eletrônico Fórum Ambiental da Alta Paulista
Electronic Journal Environmental Forum of Alta Paulista
ISSN 2966-2931 Suporte Online / Online Support - ISSN 1980-0827 Suporte CD-ROM / CD-ROM Support
Edição em Português e Inglês / *Edition in Portuguese and English* - v. 20, n. 2, 2024

Figura 3 – Análise bibliométrica de concreto contendo agregado reciclado para os anos de 2013-2022.

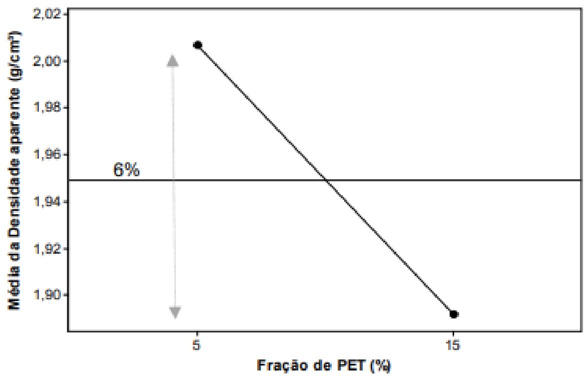


Source: MARVILA *et al.*, 2022.

In a study by Detomi *et al.* (2011), the effect of PET particles on the physical-mechanical properties of cementitious composites was presented. The results showed a reduction in mechanical properties as the proportion and size of the PET particles increased. Additionally, the introduced particles did not significantly affect the apparent porosity of the materials. The study quantified the effect of PET particles, emphasizing their potential use in non-structural civil construction applications.

Figure 4 illustrates the effect of the PET fraction on the density of the developed composites, where the average density decreases as the PET fraction increases, resulting in lighter compositions.

Figure 4 – Effect of PET Fraction on Apparent Density.

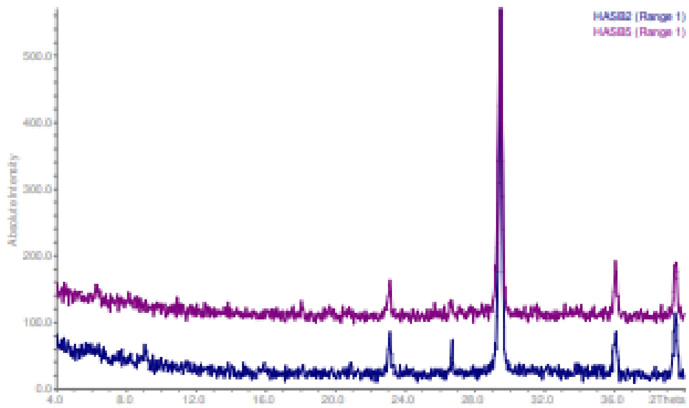


Source: DETOMI *et al.,* 2011.

A study by Hunhoff *et al.* (2018) investigated the feasibility of reusing PET waste in concrete composition, highlighting that PET recycling in civil construction is viable. The study demonstrated economic and environmental benefits while maintaining quality. Another study examined the durability of concrete containing recycled PET, monitoring degradation over time and its impact on durability properties. Results indicated improved resistance to corrosion and chemical degradation, positioning PET-PCR as a promising option for harsh environments (TANI *et al.,* 2018).

Figure 5 by Tani *et al.* (2018) presents X-ray diffraction results after Na_2SO_4 attack. Mortars modified with recycled PET showed significant resistance to sodium sulfate attacks, with corrosion resistance coefficients decreasing over time in aggressive environments.

Figure 5 – X-ray Diffraction Pattern of Samples.

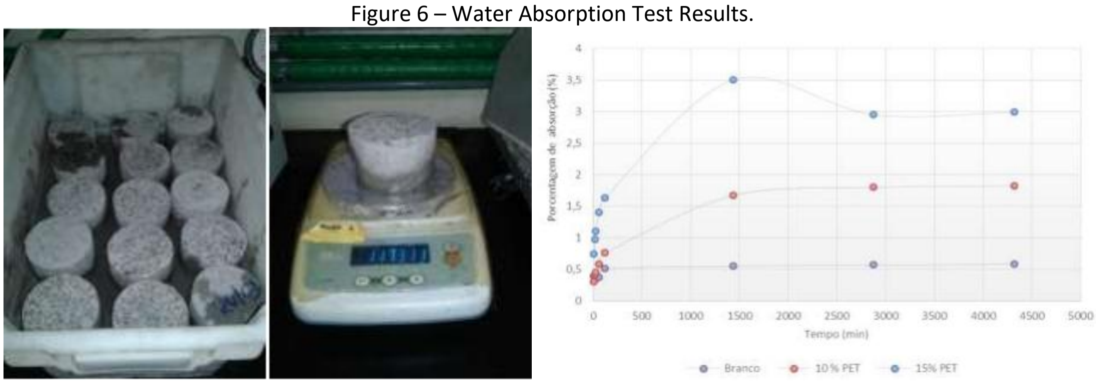


Source: TANI *et al.,* 2018.

In another study by Correa *et al.* (2019), the partial replacement of natural sand with PET-PCR in lightweight concrete was investigated. The results demonstrated a decrease in density and compressive strength with increasing PET content, along with increased water absorption.

Figure 6 shows the water absorption tests conducted by Correa *et al.* (2019), where the increase in water absorption is correlated with the amount of PET introduced into the mixture.

Figure 6 – Water Absorption Test Results.



Source: Adapted from CORREA *et al.,* 2019.

In research conducted by Correia (2021), the thermal performance of insulation panels produced with the incorporation of recycled PET was investigated. Different types of panels with varied proportions of PCR-PET in the insulating matrix were fabricated. Subsequently, the panels were subjected to standardized tests for thermal conductivity and heat resistance.

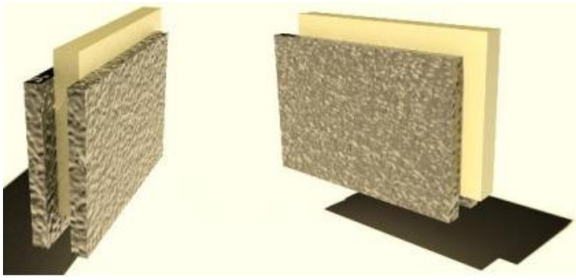
The distribution of PCR-PET in the panels was monitored, and its influence on thermal performance was quantified. The results provided evidence of the potential for

Periódico Eletrônico Fórum Ambiental da Alta Paulista
Electronic Journal Environmental Forum of Alta Paulista
ISSN 2966-2931 Suporte Online / *Online Support* - ISSN 1980-0827 Suporte CD-ROM / *CD-ROM Support*
Edição em Português e Inglês / *Edition in Portuguese and English* - v. 20, n. 2, 2024

recycled PET insulation panels to improve the energy efficiency of buildings. The author highlights that, functionally, the performance is superior to current market solutions (CORREIA, 2021). It is noted that this study aligns with previous research, such as that of Guimarães and Tubino (2004), who investigated the thermal insulation of wooden houses using external walls filled with mortar containing crushed PET bottles.

To illustrate the block model proposed in Correia's (2021) research for use in partition walls, Figure 7 is presented. It is important to note that the darker-colored panels have dimensions of 20 x 20 x 2 cm, while the lighter-colored panel measures 20 x 20 x 3 cm, resulting in a total thickness of 7 cm.

Figure 7 – PET Block Prototype.



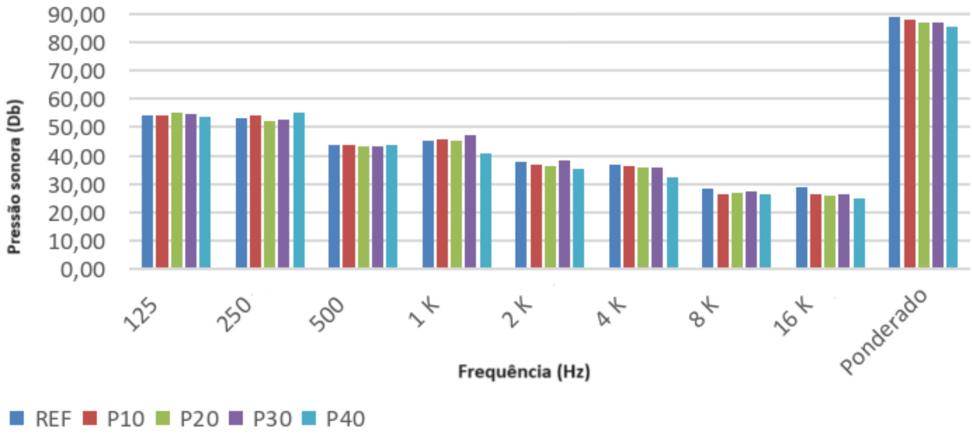
Source: CORREIA, 2021.

In the study on the acoustic performance against impact noise of floor screeds conducted by Brandão *et al.* (2024), reinforced concrete slabs with mortar screed were produced, replacing natural aggregate (sand) with PCR-PET. The screed samples were prepared with different levels of recycled PET and subjected to sound impact and acoustic insulation tests in the Universal Acoustic Test Chamber and with the Tapping Machine. The technique aimed to determine the influence of incorporating this material into the acoustic properties of the studied mortars.

The results revealed that the addition of recycled PET in the screeds can significantly improve acoustic performance, reducing the transmission of impact noise between internal environments. This suggests that these coatings can be an effective solution for improving acoustic comfort in residential and commercial buildings (BRANDÃO *et al.,* 2024). The effectiveness shown in this research in absorbing noise across various sound ranges aligns with the typical behavior of porous materials, as seen and described by Brandão (2016).

Figure 8 presents the results of the frequencies captured within the audible spectrum, considering the studied waves' frequencies in the low range between 125Hz and 500Hz, mid-range from 1kHz to 4kHz, and high-range from 8kHz to 16kHz. It is highlighted that the frequency ranges with the best performance were observed in mortars with higher concentrations of PCR-PET in the mixture.

Figure 8 – Sound Pressure Level Comparison: Impact Noise.



Source: BRANDÃO et al., 2024.

5 FINAL CONSIDERATIONS

The studies mentioned above highlight the importance and relevance of PET-PCR in the composition of cementitious materials. They provide a detailed evaluation of the influence of incorporating PCR-PET on the properties of these materials, showing its potential as a sustainable and efficient alternative in construction.

The incorporation of recycled PET in the production of cementitious materials not only reduces the demand for natural aggregates but also plays a crucial role in decreasing the amount of plastic waste destined for landfills or discarded in the environment (MEDRAN RANGEL *et al.,* 2023).

These examples demonstrate the versatility and potential of PCR-PET in creating a diverse range of sustainable cementitious materials. This innovative approach offers efficient solutions to the environmental challenges currently faced by the construction industry.

In summary, the case studies presented, along with the experimental results discussed, underscore the potential of PCR-PET as a key tool for driving the sustainable construction materials industry. By combining precise analysis with a sustainable perspective, PCR-PET stands out as an effective solution for promoting innovation and sustainability in civil construction.

Practical applications show that recycled materials, such as PET, can be integrated into various aspects of urban infrastructure. This not only promotes sustainability but also optimizes resource management (MARVILA *et al.,* 2022).

Thus, the choice to use PET-PCR in cementitious materials proves to be a sustainable option for a variety of projects, significantly contributing to reducing environmental impact and encouraging more responsible practices in construction (GALLI *et al.*, 2013).

It is important to emphasize that the use of PCR-PET plays a significant role in reducing the amount of plastic waste in the environment. Additionally, it drives the circular economy, allowing the economic revaluation of materials that were previously considered waste (NICOLAIVITS *et al.,* 2021).

Furthermore, the use of PCR-PET can represent significant cost savings in the medium and long term. By reducing the demand for traditional materials and minimizing waste disposal costs, cementitious materials with PCR-PET can offer excellent cost-effectiveness for builders and developers.

By using PCR-PET, it is possible to achieve results that are not only environmentally friendly but also technically robust and efficient. This combination of characteristics ensures that the materials produced are not only sustainable but also capable of meeting the specific and rigorous needs of current construction projects.

Thus, when considering all these aspects—sustainability, technical performance, and cost-effectiveness—it becomes clear that the application of PCR-PET in cementitious materials is a strategic and advantageous choice. It not only contributes to environmental preservation and promotes responsible practices but also offers a viable and efficient solution to the challenges currently faced by the construction industry.

Finally, this article aims to emphasize the importance and benefits of applying PCR-PET in sustainable cementitious materials. The adoption of this innovative approach not only meets the growing demands for more eco-friendly and responsible solutions but also aligns with the expectations of quality and technical performance required by the construction industry.

REFERENCES

BRANDÃO, E. **Acústica de salas.** São Paulo: Edgard Blucher, 2016

BRANDÃO, R. de S.; LIMA, J. A. P.; ALEXANDRE, J. Análise da atenuação acústica em ruídos de impacto e resistência à compressão de argamassas para contrapiso com substituição parcial de agregado natural por PET-PCR. **Scientific Journal ANAP**, *[S. l.]*, v. 2, n. 11, 2024.

CORREA, P. M.; GUIMARÃES D.; SANTANA, R. M. C. Influência da Concentração de Pet Pós-Consumo nas Propriedades Físicas do Concreto Leve. **Revista Eletrônica de Materiais e Processos**, v. 14, n. 3, 2019 140-145 ISSN 1809-8797.

CORREIA, A. R. **Avaliação do Potencial de Utilização de Fibras de PET em Materiais e Soluções Construtivas na Indústria AEC.** Dissertação (Mestrado em Engenharia Civil). Universidade do Minho - PT, 2021.

DETOMI, A. C.; LAUAR, D. F.; COSTA, H. B. A.; PASSOS, L. A.; PANZERA, T. H.; VELLOSO, V. R. EFEITO DA ADIÇÃO DE PARTÍCULAS DE PET NAS PROPRIEDADES FÍSICOMECÂNICAS DE COMPÓSITOS CIMENTÍCIO. **55º Congresso Brasileiro de Cerâmica**, 29 de maio a 01 de junho de 2011, Porto de Galinhas, PE, Brasil.

GALLI, B. *et al*. Uso de garrafas de poli-tereftalato de etileno – PET como insumo alternativo na construção de edificações residenciais. **Revista de Arquitetura IMED**, Passo Fundo, v. 1, n. 2, p. 174-181, set. 2013. ISSN 2318-1109. Disponível em: https://seer.atitus.edu.br/index.php/arqimed/article/view/424/338.

GUIMARÃES, L. E. e TUBINO R. M. C. AMBIENTAÇÃO TÉRMICA DE CASAS DE MADEIRA UTILIZANDO PAREDES EXTERNAS DUPLAS RECHEADAS COM ARGAMASSA CONTENDO CASCA DE ARROZ, RESÍDUOS DE BORRACHA (PNEU) E GARRAFA PET TRITURADA. **Congresso de Ciência e Tecnologia em Resíduos e Desenvolvimento Sustentável – ICTR,** 2004.

HUNHOFF, L. M.; RUSCHEL, A. C.; SOUSA, R. E.; VARGAS, E. L. ESTUDO DE VIABILIDADE DA REUTILIZAÇÃO DE POLIETILENO TEREFTALATO (PET) RESIDUAL NA COMPOSIÇÃO DO CONCRETO. **6º Simpósio de Sustentabilidade e Contemporaneidade nas Ciências Sociais** – 2018 1 ISSN 2318-0633.

MARVILA, M.; DE MATOS, P.; RODRÍGUEZ, E.; MONTEIRO, S.N.; DE AZEVEDO, A.R.G. Recycled Aggregate: A Viable Solution for Sustainable Concrete Production. **Revista Materials**, 15, 5276, 2022.

MASUERO, A. B. Desafio da Construção Civil: crescimento com sustentabilidade ambiental. Editorial **Revista Matéria** (Rio J.) 26 (04) 2021 https://doi.org/10.1590/S1517-707620210004.13123.

MEDRAN RANGEL, A.; WICKBOLDT STARK, F.; DE BORBA PEREIRA, P.; MEDRAN RANGEL, E.; SOUZA CASTRO, A. Os 3Rs aplicados ao plástico: Uma revisão sobre a Redução, Reutilização e Reciclagem do plástico em tecnologias ambientais. **Revista Ciência & Trópico**, v. 47, n. 2, p. 139-157, 2023.

NIKOLAIVITS E., PANTELIC B., AZEEM M., TAXEIDIS G., BABU R., TOPAKAS E., BRENNAN FOURNET M. AND NIKODINOVIC-RUNIC J 2021 Progressing Plastics Circularity: A Review of Mechano-Biocatalytic Approaches for Waste Plastic (Re)valorization. **Front. Bioeng. Biotechnol**. 9:696040. doi: 10.3389/fbioe.2021.696040.

PASSUELLO, A. C. B.; OLIVEIRA, A. F. de; COSTA, E. B. da; KIRCHHEIM, A. P. Aplicação da Avaliação do Ciclo de Vida na análise de impactos ambientais de materiais de construção inovadores: estudo de caso da pegada de carbono de clínqueres alternativos. **Revista Ambiente Construído**, Porto Alegre, v. 14, n. 4, p. 7-20, out./dez. 2014. ISSN 1678-8621 Associação Nacional de Tecnologia do Ambiente Construído.

TANI, N. K.; BENOSMAN, A. S.; SENHADJI, Y.; TAÏBI, H.; MOULI, M.; BELBACHIR, M. Prediction models of mechanical properties for pet-mortar composite in sodium sulphateaggressive mediums. **Matec Web Of Conferences**, [S.L.], v. 149, p. 01051, 2018.