Proceedings of the 10th International Conference on Civil Structural and Transportation Engineering (ICCSTE 2025)
July, 2025 | Imperial College London Conference Center, London, United Kingdom
Paper No. 202
DOI: 10.11159/iccset25.202

Physical Characterization and Compressive Strength of Lightweight Concrete with Expanded Polystyrene and Glass

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Abstract - The research study titled "Lightweight Concrete with Expanded Polystyrene and Glass" details the procedure for using expanded polystyrene and glass as substitutes for fine aggregate in lightweight concrete production. In collaboration with Lazarus & Lazarus, compression strength tests were conducted on various concrete types: conventional concrete with natural aggregates and lightweight concrete substituting sand with different combinations of expanded polystyrene and glass. Additionally, to assess the impact of additives, the same combinations were tested with 10 ml of DX2 additive and 7 ml of Imper Admix Integral. These tests, involving 33 cylindrical specimens measuring 4 inches in diameter and 8 inches in height, identified the optimal combination for compressive strength and volumetric weight. Findings indicated that integrating polystyrene and glass enhanced the density of lightweight concrete cylinders, reducing it compared to hydraulic concrete. Cost analysis also demonstrated that lightweight concrete had a lower cost per square meter than hydraulic concrete.

***Keywords*:** additive, Imper Admix Integral additive, ASTM standards, volumetric weight, compressive strength.

1. Introduction

Due to the impact generated by the construction industry, it is necessary to seek sustainable alternatives that help reduce the percentages of extraction of stone materials, such as sand, for the manufacture of lightweight concrete.

Lightweight concrete has emerged as an alternative in the construction industry as a method of reducing dead loads in structures and increasing project cost efficiency, with the incorporation of lightweight aggregates that replace percentages of sand such as expanded polystyrene and 3/8" glass [1], [9], [10].

In this context, this research article will demonstrate the behavior of lightweight concrete when using different percentages of recyclable materials, such as expanded polystyrene and glass, to partially replace the fine aggregate in the mix.

For the development of the research work, the Civil Engineering laboratory, belonging to the Faculty of Engineering (FI) of the Central American Technological University (UNITEC), was used, with the objective of determining the compressive strength and volumetric weight of each test piece, to establish a comparison between the physical and mechanical characteristics and determine the possibility of replacing the fine aggregate in percentage terms with recyclable materials such as expanded polystyrene and crushed glass, with and without additives [11].

2. Problem Statement

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Sustainable development is characterized by meeting the needs of people without risking their future. Research has been carried out in the construction industry sector showing the results of lightweight mixtures with recycled materials that act as alternatives to prefabricated stone aggregates to improve the impact generated by industry [2].

2.1. Background of the Problem

Concrete manufacturing involves high consumption of energy and natural resources, resulting in the emission of large amounts of greenhouse gases (GHG). In addition, the life cycle of buildings, from construction to demolition, generates a large amount of waste [3], [12].

Given the impact of this industry, the use of recyclable construction materials that contribute to the sustainable aspect at a global level has been actively promoted [2], [13].

2.2. Problem Definition

In the study carried out in 2019, the environmental impact on the industry caused worrying results at a global level, which is why today, the search for alternative materials to those commonly used in the industry has been actively promoted [3].

The building construction and cement manufacturing sectors are responsible for a significant share of emissions and demand for raw materials worldwide. Indeed, 40% of global anthropogenic GHG emissions and 40% of raw materials are attributed to the construction industry, while global annual concrete production is close to 25 gigatons, or 3.8 tons per person per year [3].

2.3. Justification

The initiative to use waste materials to manufacture lightweight concrete, such as glass and polystyrene, is to contribute to the reduction of the environmental impact caused by the construction industry, which helps to promote new practices within this sector that contribute to the improvement of the mechanical properties of some materials that are used today [3].

3. Methodology

3.1. Approach

[4] In mixed research, the concurrent method is an approach that involves simultaneous collection and analysis of qualitative and quantitative data. This design allows for the integration of multiple perspectives and approaches in single research.

The research approach is mixed, since it is required to compare the characteristics and qualities of lightweight concrete with hydraulic concrete and with concrete with traditional lightweight additives. In addition, the necessary calculations will be made for the dosage of lightweight concrete with recyclable materials.

To evaluate the variables described in the previous section, the different dosages used must be determined where certain percentages of fine aggregate are replaced in the mixture.

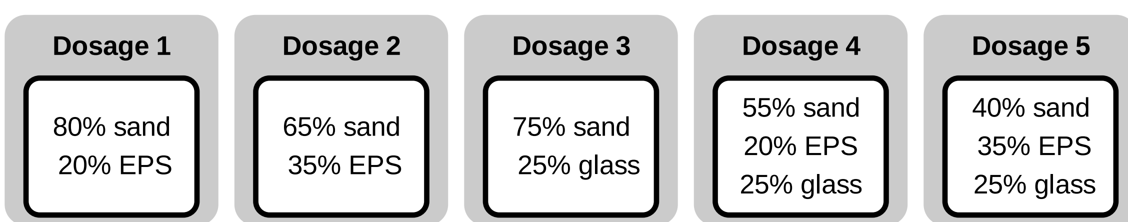

Fig. 1: Design Dosages.

The mechanical and physical properties of lightweight concrete are two of the main dependent variables in the research. These will be affected by the dosages and properties of the aggregates used.

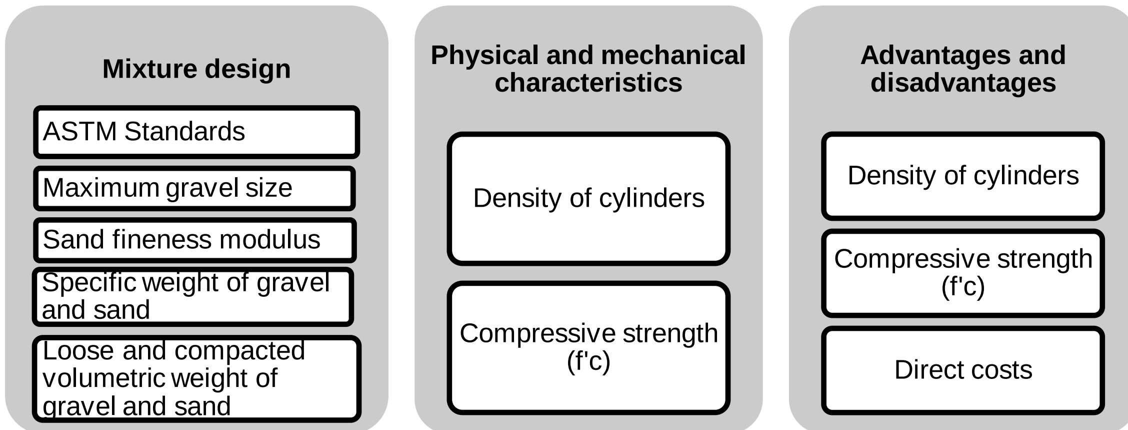

Fig. 2: Research Variables.

3.2. Applied Techniques and Instruments

Scientific research techniques are methods that have been tested in practice, designed to obtain and convert relevant information that help solve problems in various scientific disciplines. Primary and secondary sources were used, among which there are different types of instruments, among which the interviews, research in secondary sources and the use of past research to obtain information relevant to the research stand out.

3.2.1. Interviews

The interview is an invaluable technique in qualitative research that helps us gather information [5]. The interviews were conducted with experts in the field of additive use, and in both cases, they were representatives of the Lazarus and Lazarus companies. These interviews were conducted via videoconference and in person at UNITEC laboratories.

Fig. 3: Data from Interviewed Professionals.

3.2.2. Research in Secondary Sources

The secondary sources of the essay include books and articles that analyze the work or research of others, such as journal articles, academic books, laboratory tests, and unit sheets. Articles from journals such as SciELO, Redalyc, and Google Scholar were used. Academic books were found at UNITEC's Learning and Research Resources Center (CRAI). The laboratory tests were based on the UNITEC manual for concrete laboratory testing, which is duly configured under ASTM regulations.

3.2.3. Laboratory Tests

The analyses carried out in the UNITEC Civil Engineering laboratory helped to identify the characteristics of the material to be used in the mixture of dosages, which include gravel and sand. Once these values have been established, the dosage to be used is calculated, respecting the parameters of the ACI-211 standard.

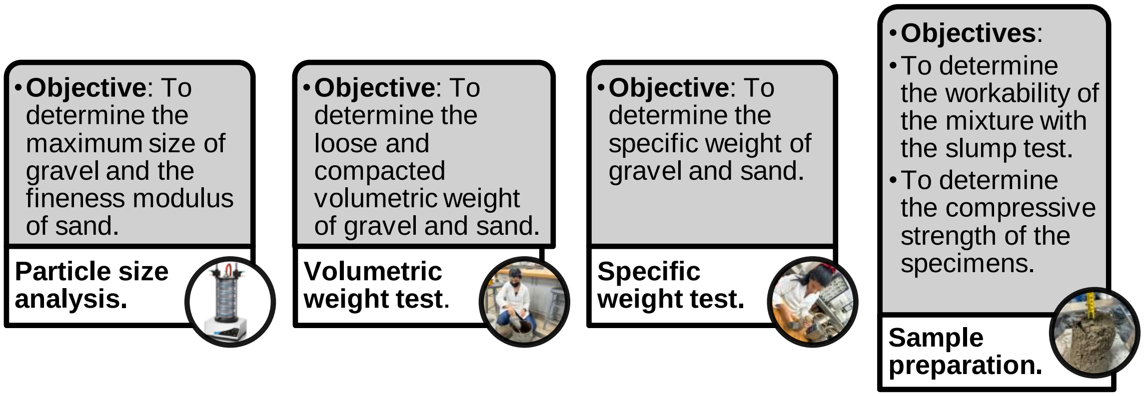

Fig. 4: Laboratory Tests Performed on Base Materials.

3.3. Study Methodology

This section will detail the procedure carried out, describing each of the stages and steps implemented for data collection and analysis. The techniques used will be explained, providing a clear overview of the methodologies selected and the justification for their use in relation to the specific objectives of the research.

3.3.1. Background of Research

[6] The review of the research background provides a comprehensive overview of previous studies, theories, and significant findings that have influenced the knowledge and development of the theoretical framework of the research. These include different types of sources, for example, secondary sources, laboratory manuals, or virtual technologies.

3.3.2. Design Considerations

Design considerations are essential to ensure the effectiveness and accuracy of any investigation. This section details the principles and criteria that guided the planning of the study, including the selection of methodologies using primary sources, and the experimental structure and procedures for data collection and analysis using laboratory test results.

For the dosage, a 3000-psi concrete with a dosage of 1:2.3:3.5 (W/C: 0.63) was considered.

This dosage was generated because of the results obtained in the laboratory tests of granulometry, specific weight and volumetric weight that were carried out to determine the qualities of the fine and coarse aggregates used in the mixtures that were the object of the laboratory tests.

Table 1: Proportions of recyclable material without additives.

Sample	Sand	Expanded Polystyrene (EPS)	Glass
1	80%	20%	---
2	65%	35%	---
3	75%	---	25%
4	55%	20%	25%
5	40%	35%	25%

Table 2: Dosages of recyclable material with additive.

Sample	Sand	Expanded Polystyrene (EPS)	Glass	Water	Additive "DX2"	Additive "Imper Admix Integral"
1	80%	20%	---	85%	10 ml	7 ml
2	65%	35%	---	85%	10 ml	7 ml
3	75%	---	25%	85%	10 ml	7 ml
4	55%	20%	25%	85%	10 ml	7 ml
5	40%	35%	25%	85%	10 ml	7 ml

3.3.3. Considerations in Percentages

Considerations regarding the percentages of recyclable material were analyzed based on studies conducted on expanded polystyrene and the use of crushed glass for the partial replacement of fine aggregate. These studies determined optimal ranges for the use of each material separately.

It has been observed that the replacement of up to 35% or less of the fine aggregate with expanded polystyrene helps to reduce the density of concrete but can affect its compressive strength [7], [14].

On the other hand, the replacement of 25% of the fine aggregate with recycled glass produces good results in terms of strength. These conclusions serve as a basis for optimizing the properties of lightweight concrete, using both materials to seek to reduce its density without compromising structural strength [8], [15].

4. Results and Analysis

This section presents the results obtained from the comparison of weights, the compressive strength tests of the cylinders and the direct costs of each combination analyzed. The physical and mechanical properties of the concretes and their viability in construction are analyzed. The challenges presented throughout the research are also expressed.

4.1. Weight comparison

The weight comparison between normal concrete and lightweight concrete reveals significant differences that influence their use and applications. Therefore, a comparison will be made between the weights of the different concrete combinations to assess whether the use of polystyrene helps in reducing the weight of the concrete. The samples with and without the additive are compared with normal hydraulic concrete, showing that 35% polystyrene considerably reduces the weight of the concrete in both cases, with differences of 28.36 and 14.19 respectively. However, the additive increases the density in the case of 25% glass concrete, making it unsuitable for manufacturing lightweight concrete.

4.1.1 Comparison of sample weights with and without additive

It is necessary to analyze the contribution of materials in search of new options for lightweight concrete. The following graphs show the average densities obtained for each type of concrete sample. It can be noted that there was a decrease when implementing recyclable materials.

The greatest decrease in terms of density occurs in the combination of 35% expanded polystyrene with and without additives, having 14.19 and 28.36 kilograms per cubic meter, respectively.

It should be noted that the combination of 35% expanded polystyrene and 25% glass with additives shows a notable decrease due to the addition of additives, but not in all cases since in the 25% glass sample the use of additives only increases the density of this in comparison to that of hydraulic concrete.

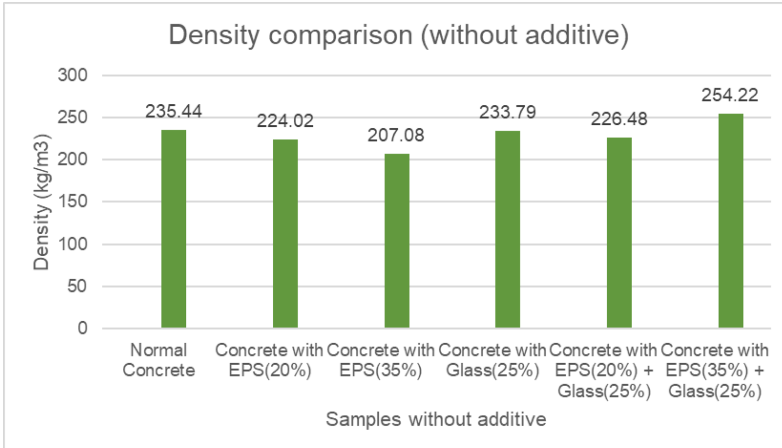

Fig. 5: Densities of samples without additive.

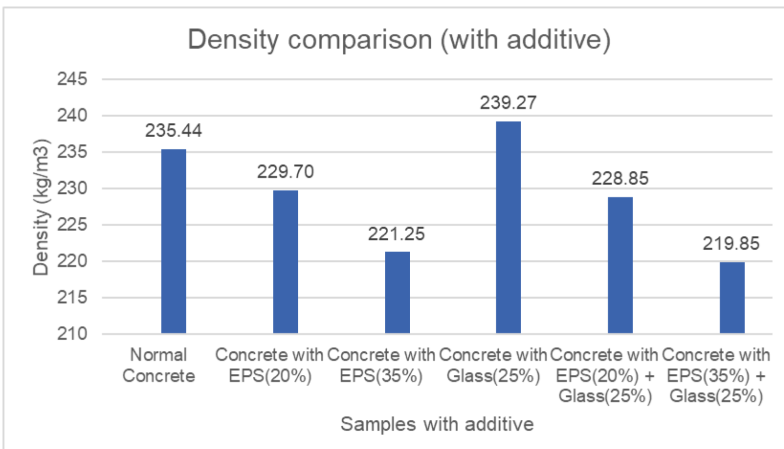

Fig. 6: Densities of samples with additive.

4.2. Compression Strength Test (f'c)

The compressive strength of concrete is crucial to assess its load-bearing capacity. It is typically carried out in cured cylinders, which are subjected to loads until they break. This strength is expressed in megapascals (MPa) or pounds per square inch (psi), providing key information about the quality and durability of the material. For this test, tests were carried out on cylinders with dimensions of 4x8 inches, with different percentages of recyclable material and comparing them with the compressive strength of normal hydraulic concrete.

To determine that the cylinder strengths met expectations, hydraulic concrete samples were manufactured as a comparative factor between the different combinations of lightweight concrete. Using a vernier caliper and a meter, 3 measurements are made on the different faces of the cylinder, and the average between the diameters and heights is taken. Finally, the area is calculated.

4.2.1 Comparison of resistances with and without additive

Regarding strengths, the results were evaluated, and it was shown that, on average, the strength of hydraulic concrete shows a value of 1,747.27 pounds per square inch. It is notable that the mixtures with 25% glass without additives and 20% polystyrene plus 25% glass with additive are those that exceed the average of hydraulic concrete and reach a range of 2,000 psi [16].

However, the inconsistencies that are presented, regarding the increase in expanded polystyrene, the strength is below the average of hydraulic concrete. And indeed, in the case of 35% polystyrene in conjunction with glass, the compressive strength of concrete increases. The use of additives presents improvements in the combinations of polystyrene alone and in conjunction with glass, however, it should be noted that glass alone has better mechanical properties than when additives are added [17].

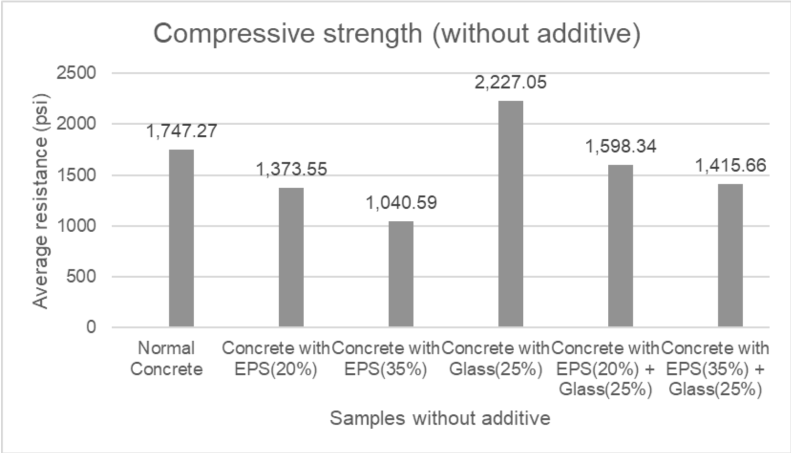

Fig. 7: Average compressive strengths, without additive.

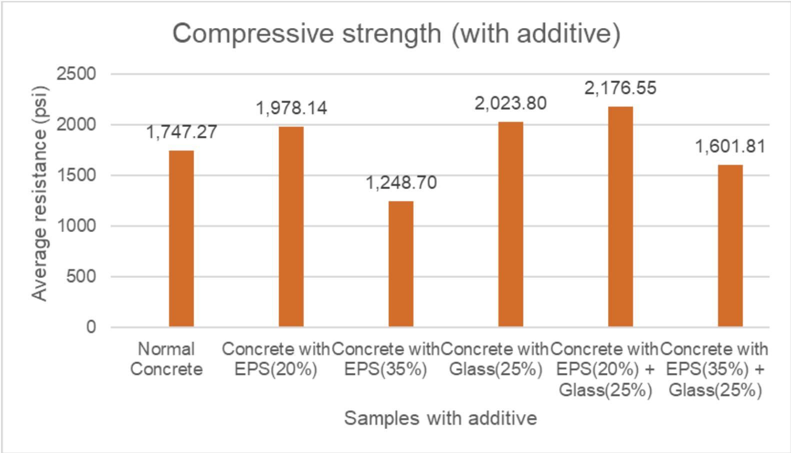

Fig. 8: Average compressive strengths, with additive.

4.3. Direct Manufacturing Costs

Within this section, interviews were conducted, and cost sheets were collected from the Honduran Social Investment Fund (FHIS) to determine the direct costs associated with the manufacture of a 10-centimeter-thick lightweight slab. The results will be compared to those for a normal 3,000-pound-per-square-inch concrete slab to estimate whether it is feasible to use recycled materials in the manufacture of these slabs.

4.3.1 Direct costs with and without additive

Joint evaluations were carried out with the aim of establishing the direct cost related to the manufacture of various combinations of lightweight concrete, using as a base the costs of a 10 cm thick concrete slab, according to data from the Honduran Social Investment Fund. After the investigation, a notable decrease in manufacturing costs was observed, which shows the most significant decrease of less than $1 in concrete, in the case of the combination of 35% polystyrene and 25% glass [18].

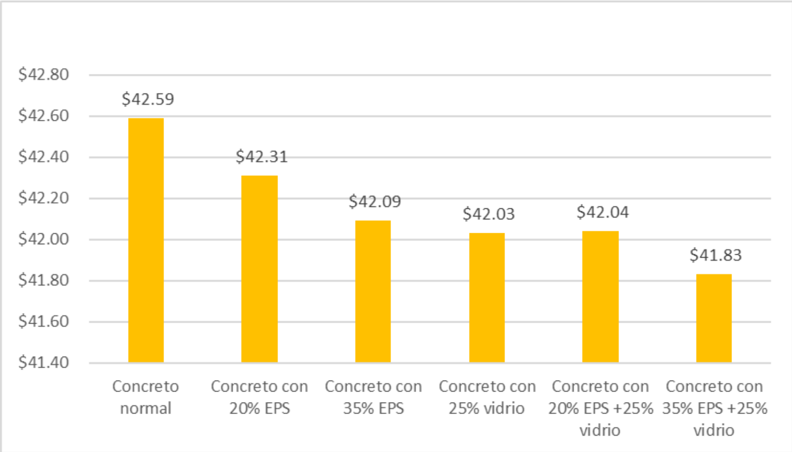

Fig. 9: Unit price (slab-10cm/m2); concrete without additives.

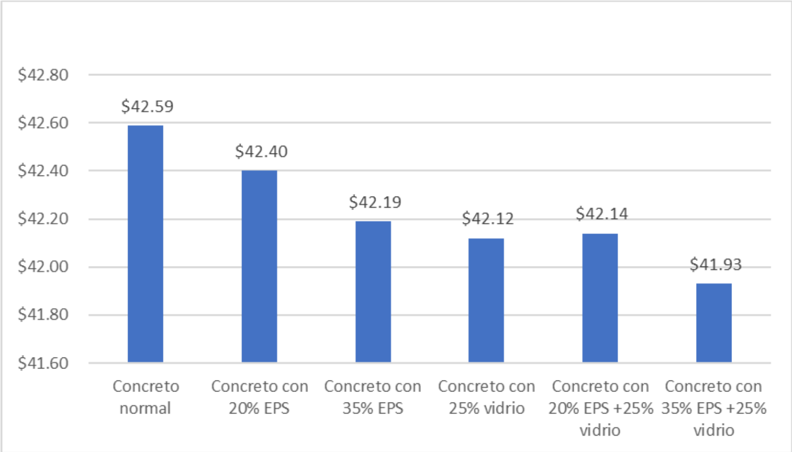

Fig. 10: Unit price (slab-10cm/m2); concrete with additives.

4. Conclusion

The study on lightweight concrete highlights its usefulness in the construction of elements such as slabs between floors and smaller structures, thanks to its lower density compared to hydraulic concrete [19]. The research used standardized tests by the American Society for Testing and Materials to evaluate the compressive strength and density of the material. The cost analysis was based on data from the Honduran Fund for Social Investment, concluding that replacing 35% of sand with expanded polystyrene and 25% with crushed glass is more economical and reduces direct costs.

An adverse effect on compressive strength was observed when increasing the percentage of polystyrene, while the combination of 20% expanded polystyrene with glass showed a significant increase in this property when the use of additives was implemented.

It is recommended to leave the investigation open and in future studies the use of 6 x 12-inch cylinders for the tests, or to ensure that the appropriate heads for the 4 x 8-inch cylinders are available, since the lack of the latter affected the obtaining of the desired results due to failures in the contact surfaces. According to the data obtained, it is suggested that lightweight concrete samples with 20% expanded polystyrene and 25% glass, using additives, could be suitable for the manufacture of lightweight slabs, thus overcoming the compressive strength of hydraulic concrete [20].

Acknowledgments

Special thanks are given to Eng. Juan Carlos Reyes Zúniga (Technical Coordinator of the Civil Engineering Laboratory of UNITEC) for all his logistical support for the use of the facilities and equipment necessary to perform all the tests required in this research, and also, special thanks to the specialized company of the Honduran construction industry "Lazarus & Lazarus", who through Arch. France Lindsey Higgins Luttich and Eng. Alejandro Enrique Licona Gutiérrez, provided all the technical and logistical support in the configuration of concrete mixes, use and implementation of specialized materials, such as polystyrene, glass and additives.

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