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Evaluation of the Mechanical Properties of Hydraulic Concrete Reinforced with Recycled Polyethylene Terephthalate

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Abstract

This study evaluates the mechanical properties of hydraulic concrete reinforced with recycled Polyethylene Terephthalate (PET) plastic fibers, addressing both construction performance and environmental sustainability. While concrete is a widely used material for its strength and durability, the increasing production and disposal of PET waste present significant ecological challenges. Incorporating recycled PET fibers into hydraulic concrete offers a dual benefit: reducing plastic waste while potentially improving the material's mechanical performance. Despite prior research on plastic additives in concrete, limited attention has been given to the specific mechanical behavior of hydraulic concrete reinforced with recycled PET fibers. The main objective of this research is to analyze the effect of PET fiber incorporation on compressive strength through controlled laboratory experiments. Concrete mixes with varying fiber proportions were prepared and subjected to compressive strength testing, with results compared to standard concrete performance. Beyond technical evaluation, the study also situates its findings within the framework of the Sustainable Development Goals (SDGs), highlighting PET recycling as a strategy for advancing sustainable construction and waste management. The results are expected to inform the development of more sustainable and efficient concrete formulations while contributing to broader environmental conservation efforts.

Keywords: Hydraulic Concrete; Recycled PET Fibers; Mechanical Properties; Plastic Waste Recycling; Sustainable Construction

INTRODUCTION

Hydraulic concrete is a fundamental material in construction due to its strength and durability, being widely used in various structures. However, the production and disposal of plastic waste, such as Polyethylene Terephthalate (PET), generate a significant environmental impact, posing a global challenge in waste management. In this context, incorporating recycled PET plastic fibers into hydraulic concrete emerges as a promising alternative to address this issue while aiming to enhance the material's mechanical properties, such as compressive strength, tensile strength, toughness, and durability.

Despite advances in research on the use of plastic additives in concrete, there is a knowledge gap regarding the specific evaluation of the mechanical properties of hydraulic concrete reinforced with recycled PET fibers. Factors such as fiber proportions, their distribution within the concrete matrix, the water-cement ratio, and curing time are critical to understanding the behavior of this composite material. Therefore, a systematic and comprehensive evaluation is crucial to determine the technical feasibility of this solution and its potential to contribute to more sustainable construction practices.

The purpose of this research was to evaluate the mechanical properties of hydraulic concrete reinforced with recycled PET plastic fibers through laboratory tests analyzing the influence of different fiber proportions and distributions, as well as other relevant factors. The results of this study aim to provide a scientific and technical basis for implementing this material in the construction industry, promoting the reduction of plastic waste and the development of sustainable solutions aligned with the Sustainable Development Goals (SDGs).

In terms of scope, the research will be conducted between June 2023 and March 2024, with laboratory tests performed at the soils and materials laboratories of the University City of UNIVO, located in San José, Quelepa, San Miguel, El Salvador. From a theoretical perspective, it will be based on prior studies related to Green Architecture, a sustainable design approach that minimizes the environmental impact of construction (Taracena, 2010), as well as updated literature on the use of PET in construction.

The general objective of this research is to conduct compressive strength tests to evaluate the influence of recycled PET fibers on the concrete's ability to withstand compressive loads. Specific objectives include designing and preparing samples with different fiber proportions, conducting laboratory tests, and performing a comparative analysis of the results against reference values for conventional hydraulic concrete. This is expected to contribute to the development of innovative, sustainable, and economically viable construction alternatives that address both environmental challenges and the needs of the construction industry.

PET, a petroleum-derived polymer composed of modified ethylene glycol and terephthalic acid, has been widely used since 1976 in the manufacture of lightweight, durable, and recyclable containers, primarily for beverages (Pacas, 2018). Its physical properties, such as high wear resistance, dimensional stability, chemical resistance, and good dielectric characteristics, have made it a key material for containers and textile fibers. However, its mass production generates a significant environmental impact, as PET takes approximately 700 years to degrade, requires large amounts of oil (24 million gallons per billion bottles), and releases toxic substances during manufacturing (Negocios verdes, 2016). Globally, plastic pollution, with 335 million tons produced in 2016, severely affects marine and terrestrial ecosystems, entering the food chain and posing risks to human health (Plastics Europe, 2016; Jambeck & Lavender, 2017).

PET recycling presents a solution to mitigate this environmental impact. In El Salvador, PET has seen increased demand in the recycling market, gaining significant relevance between 2003 and 2005 (Meléndez Avalos, Ramírez Flores, & Meléndez, 2006). There are three main ways to recycle PET for construction: depolymerization into polyester resin, use as reinforcing fibers in concrete, and partial replacement of aggregates (Pari & C.A., 2016). Recycled PET fibers in hydraulic concrete improve mechanical properties, such as compressive strength, tensile strength, abrasion resistance, and impact resistance, while also reducing plastic shrinkage cracking and permeability (National Ready Mixed Concrete Association, 2020). Additionally, eco-blocks made from ground PET combined with Portland cement offer advantages such as lightness, fire resistance, and thermal insulation, serving as a sustainable alternative for non-structural walls.

The incorporation of recycled PET fibers into hydraulic concrete aligns with the principles of Green Architecture, promoting sustainable development that minimizes environmental impact (Osorio, 2011). This approach not only addresses the issue of plastic waste but also offers innovative, economically viable, and accessible construction solutions, particularly for vulnerable communities, contributing to pollution reduction and efficient resource use.

METHODS

The type of research conducted is Technological Innovation and Applied Research.

For data collection, tests were carried out at the soils and materials laboratory of UNIVO, where the concrete slump test was performed to assess the fluidity of the mix. Additionally, concrete cylinder tests were conducted to verify the strength of the concrete mixed with shredded plastic, which was compared with traditionally constructed materials. This approach allowed for the evaluation of the quality of the manufactured materials and the determination of the optimal dosage.

Plastic bottles were collected with the support of Embotelladora Electropura de Agua las Perlitas. The bottles were prepared by removing labels and ensuring they were free of contaminants such as grease, gasoline, and organic or inorganic matter, before being shredded using the institution's plastic shredding machine.

A study of aggregates was conducted to develop the concrete mix design, targeting a structural concrete strength of 280 kg/cm². Three percentages of shredded PET—5%, 10%, and 20%—were added to the dry weight of the materials to evaluate and compare results.

A concrete design of 280 kg/cm² was developed, although the resulting concrete is considered non-structural, as it is not recommended for load-bearing structures due to its experimental nature.

Sand and gravel were transported for testing aggregates, which facilitated the creation of the concrete mix design based on the available materials.

Figure 1. Process of making concrete with PET.

The concrete mix design used had a strength of 280 kg/cm². The cylinders were submerged in water, a process known as concrete curing. During this period, the material gains the necessary strength. After 7 days, it achieves 70% of its strength, allowing for the first test. This is followed by testing at 14 days, and concluding at 28 days, when it reaches 100% strength, at which point the final test is conducted.

Figure 2. The cylinders were removed from the water to conduct strength tests, which were performed at 7 and 28 days of curing.

Figure 3. Data collection from concrete cylinders.

The measurements of the cylinder were taken, including diameter, height, and weight, for cylinders with 5% PET, 10% PET, and conventional concrete cylinders with a strength of 280 kg/cm².

Figure 4. Data collection from concrete cylinders subjected to compression testing.

These tests are used to determine the concrete's strength in kilograms per square centimeter, conducted at 7 days and 28 days for both PET-reinforced concrete and conventional concrete.

RESULTS

Table 1. Sampling and compression control of cylinders.

Test date	Test age	Diameter (cm)	Average diameter	Cross-sectional area (cm²)	Weight (g)	Height (cm)	Load (kg)	Strength (kg/cm²)	Percentage of PET
27/04/2024	7	15.18 15.14	15.16	180.27	11782	30.5	20007.15	111.0	5%
18/05/2024	28	15.16 15.18	15.17	180.86	11904	30.4	27624.91	152.7	5%
27/04/2024	7	15.19 15.22	15.20	181.46	11258	30.3	12766.88	70.4	10%
18/05/2024	28	15.20 15.18	15.19	181.46	11412	30.5	18291.70	100.8	10%
27/04/2024	7	15.19 15.20	15.19	181.46	12532	30.4	28101.03	154.9	0%
27/04/2024	7	15.24 15.20	15.22	182.06	12488	30.3	28709.05	157.7	0%
18/05/2024	28	15.22 15.25	15.23	182.06	12522	30.6	46808.30	257.1	0%
18/05/2024	28	15.25 15.26	15.25	182.65	12564	30.7	44904.35	245.8	0%

• **Specimen 1** – concrete with 5% PET at 7 days: its height was 30.5 cm, diameter 15.18 cm, area 180.27 cm², weight 11,782 g, load 20,007.15 kg, and its compressive strength was 110 kg/cm².

• **Specimen 2** – concrete with 5% PET at 28 days: its height was 30.4 cm, diameter 15.17 cm, area 180.86 cm², weight 11,904 g, load 27,624.91 kg, and its compressive strength was 152.7 kg/cm².

• **Specimen 3** – concrete with 10% PET at 7 days: its height was 30.3 cm, diameter 15.20 cm, area 181.46 cm², weight 11,258 g, load 12,766.88 kg, and its compressive strength was 70.4 kg/cm².

• **Specimen 4** – concrete with 10% PET at 28 days: its height was 30.5 cm, diameter 15.19 cm, area 181.46 cm², weight 11,291.70 g, load 18,291.70 kg, and its compressive strength was 100.8 kg/cm².

• **Specimen 5** – conventional concrete at 7 days: its height was 30.4 cm, diameter 15.19 cm, area 181.46 cm², weight 12,532 g, load 28,101.03 kg, and its compressive strength was 154.9 kg/cm².

• **Specimen 6** – conventional concrete at 7 days: its height was 30.3 cm, diameter 15.22 cm, area 182.06 cm², weight 12,488 g, load 28,709.05 kg, and its compressive strength was 157.7 kg/cm².

• **Specimen 7** – conventional concrete at 28 days: its height was 30.6 cm, diameter 15.23 cm, area 182.06 cm², weight 12,522 g, load 46,808.30 kg, and its compressive strength was 257.1 kg/cm².

• **Specimen 8** – conventional concrete at 28 days: its height was 30.7 cm, diameter 15.25 cm, area 182.65 cm², weight 12,564 g, load 44,804.35 kg, and its compressive strength was 245.8 kg/cm².

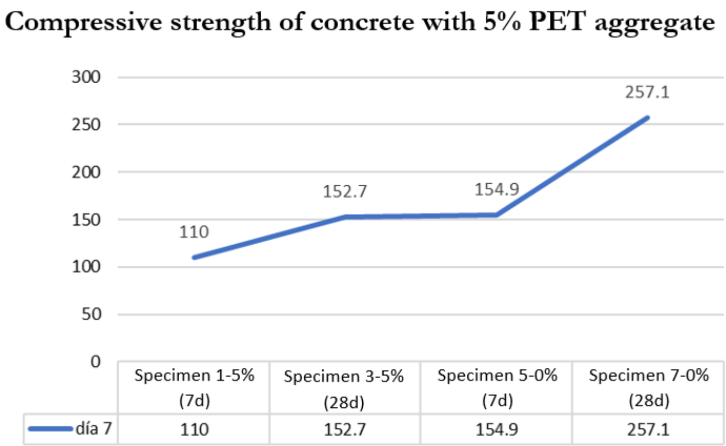

Figure 5. Results of the compressive strength test for concretes with 5% PET aggregate.

Analysis: The results of the concrete with 5% PET aggregate from day 7 to day 28 were as follows: Specimen 1 reached a compressive strength of 110 kg/cm² on day 7, specimen 3 reached 152.7 kg/cm² on day 28, specimen 5 — which is conventional concrete — reached 154.9 kg/cm² on day 7, and specimen 6, also conventional concrete, reached 257.1 kg/cm² on day 28.

It is important to note that specimen 1 showed a low strength level on day 7 for a 280 kg/cm² concrete, and specimen 3, at 28 days, had almost the same strength level as conventional concrete at 7 days. This indicates that this type of concrete is not recommended for reinforced or structural concrete applications. However, it could be used for sidewalks, as block fill mortar, or for first-level slabs to install ceramic flooring.

Specimens 5 and 7 did not contain PET; they are conventional structural concretes rated at 280 kg/cm². On day 7, specimen 5 achieved 154.9 kg/cm² of compressive strength, slightly higher than the maximum strength reached by specimen 3, which did contain PET. Specimen 7 reached a maximum strength of 257.7 kg/cm². While this did not reach its theoretical maximum strength, it is still considered suitable for construction. Nevertheless, the failure to reach maximum strength similarly impacts the performance of concretes that do contain PET plastic.

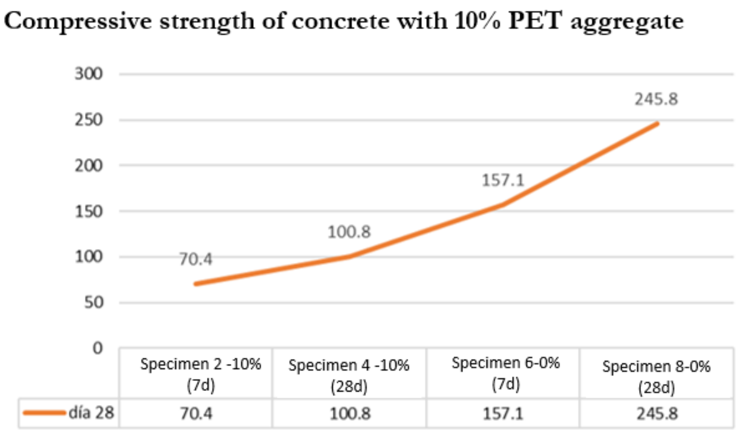

Figure 6. Results of the compressive strength test for concretes with 10% PET aggregate.

Specimen 2 reached a compressive strength of 70.4 kg/cm² on day 7, and specimen 4 reached 100.8 kg/cm² on day 28. Specimen 5, which is conventional concrete, reached 157.1 kg/cm² on day 7, and specimen 8, also conventional concrete, reached 245.8 kg/cm² on day 28.

On day 7, specimen 2 did not reach the minimum strength required to be considered structural concrete, and by day 28, it did not achieve adequate final strength when compared to specimens 6 and 8, which were made with conventional concrete. Although specimens 6 and 8 did not reach the standard compressive strength of 280 kg/cm², they are still considered suitable for construction.

This concrete with 10% PET is not suitable for structural applications, such as floor slabs, footings, columns, beams, etc. It is not recommended for use in ceramic floor slabs; however, it can be used as block fill mortar.

At the beginning of the research tests, three concrete mix designs were prepared with 5%, 10%, and 20% PET:

5% PET concrete: This mix can be used for non-structural constructions, such as sidewalks, ceramic floor slabs, and block fill mortar.

10% PET concrete: This mix has many deficiencies, including a lack of minimum strength and low workability. It is not recommended even as non-structural concrete, but it may be classified as mortar for block filling.

20% PET concrete: This mix causes segregation of all materials during preparation, making it inapplicable due to the excessive amount of PET plastic.

The observed relationship between PET content and material performance is as follows:

Higher PET content = lower concrete strength

Lower PET content = higher concrete strength

DISCUSSION

Polyethylene terephthalate (PET) is one of the most widely used plastics globally, particularly for packaging production due to its physicochemical properties: strength, lightness, thermal stability, and recyclability (Pacas, 2018). However, its intensive use has led to an environmental crisis. It is estimated that over 6.4 million tons of plastic waste enter the ocean each year, affecting marine biodiversity and human health (UNEP, 2009; Jambeck & Lavender, 2017). PET's slow degradation, which can take up to 700 years, has driven research into its effective reuse.

Various studies have shown that recycled PET can be incorporated as an additive or aggregate in concrete mixtures, providing benefits such as reduced plastic cracking, lower moisture absorption, and improved impact resistance (Pari & Ca, 2016; National Ready Mixed Concrete Association, 2020). In particular, the use of PET synthetic fibers in concrete enhances the material's mechanical behavior, especially during initial curing, though its performance as a structural material remains limited.

In a study conducted in El Salvador, ground PET was added at proportions of 5%, 10%, and 20% to a hydraulic concrete mix with a target strength of 280 kg/cm^2. The results indicated that:

The 5% PET mix achieved a strength of 152.7 kg/cm^2 at 28 days, comparable to conventional concrete at 7 days.

The 10% PET mix only reached 100.8 kg/cm^2, while the 20% PET mix caused material segregation, making it unsuitable even for non-structural uses.

These findings confirm an inverse relationship between PET content and concrete strength, consistent with previous literature (Rahman et al., 2018). However, low-percentage PET mixes (5%) proved viable for non-structural elements such as sidewalks, ceramic tile bases, or filler mortar, offering a useful alternative for plastic waste reduction.

The use of recycled PET in construction, particularly in developing countries like El Salvador, represents a strategy for advancing toward a circular economy. Although demand for recycled PET in the country remains low (Meléndez et al., 2006), projects like this one could stimulate new markets and sustainable production models, reducing reliance on virgin materials, energy consumption, and pollutant emissions.

However, significant challenges must be addressed, including:

Limited infrastructure for advanced recycling (e.g., chemical recycling for food-grade use).

Lack of local technical regulations governing the use of recycled aggregates in construction.

Need for initial investment in machinery and technical validation processes.

The use of recycled PET not only helps mitigate environmental pollution but also enables the development of low-cost materials with acceptable technical performance for social housing projects, aligning with the principles of sustainable development (Osorio, 2011).

CONCLUSION

The most favorable PET-concrete design for practical use is the 5% PET mix, which is considered suitable for non-structural concrete. The 10% PET mix can be used as mortar for block filler, while the 20% PET mix is unusable.

According to strength tests, concrete with crushed PET bottles exhibits reduced strength due to the plastic's final structure. While PET fibers are commercially available for concrete reinforcement, these fibers have a different structure—thinner and thread-like—which improves adhesion and creates a more integrated system.

The resulting strength tests confirm that higher PET content in the mix design leads to lower strength, whereas lower PET content yields higher strength.

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