UNIVERSIDAD SAN FRANCISCO DE QUITO USFQ

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Estudio comparativo de métodos experimentales y analíticos sobre usos de plásticos PET y FRP en el hormigón

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RESUMEN

El presente trabajo fue realizado por Harold David Jarrín Velasco, Daniel Alejandro Solís León y Carlos David Vélez Loaiza, con códigos de estudiante 00205619, 00206056, 00215935 respectivamente, en conjunto se determinó que el uso de plásticos ha estado aumentando desde la revolución industrial donde "Se estima que se han producido cerca de 8,300 millones de toneladas métricas (Mt) de plásticos vírgenes hasta la fecha" (Portilla Jiménez, J. G. (2022).) La gran cantidad de plásticos ha permitido ciertas facilidades para los seres humanos, sin embargo, ponen en riesgo el hábitat donde nos desarrollamos como especie, no solo por las emisiones de carbono que son necesarias para desarrollarlos, sino también porque no son residuos orgánicos, lo que causa una gran contaminación ya que no son biodegradables, "Los plásticos tardan alrededor de 180 años en degradarse y se utilizan en la industria, en la vida diaria son productos con una capacidad limitada para autodestruirse, por lo tanto, permanecen durante muchos años como residuos" (López-Aguirre, J. F., Pomaquero-Yuquilema, J. C., & López-Salazar, J. L. (2020)), por lo tanto, vivir en un país tan biodiverso requiere un cambio en el manejo de estos residuos, "El país debe iniciar su cambio cultural no solo en la gestión integral de residuos, sino que las políticas dirigidas a la producción y la importación deben estar alineadas con el cumplimiento de los principios de la Economía Circular y el desarrollo sostenible" (Portilla Jiménez, J. G. (2022).)

"Los resultados indican que los ciudadanos del área urbana del cantón Guayaquil tienen una percepción ambiental del 59.70%, una cognición ambiental del 41.92%, un comportamiento proambiental del 76.50%, un nivel de conciencia del 60.68% y el plástico de un solo uso que se utiliza con más frecuencia es la bolsa de plástico tipo camiseta con un 31.25%. A pesar de la cognición y la conciencia ambiental promedio,

los ciudadanos del área urbana del cantón Guayaquil están dispuestos a participar y apoyar estrategias para minimizar el consumo de plásticos de un solo uso" (Cobos Pazmiño, V. P. (2021)), el estudio realizado por Cobos Pazmiño muestra un panorama alentador, ya que hay una iniciativa para apoyar estrategias que minimicen el consumo de plásticos.

El propósito del presente Proyecto Integrador es responder a la pregunta: ¿Qué se sabe sobre el uso de plásticos en el concreto?, donde se investigaron una serie de fuentes de acuerdo con las siguientes combinaciones de palabras: uso de fibras de PET recicladas en el concreto, tipos de plásticos utilizados en dosificación de concreto, fibras plásticas como aditivos, agregado plástico reciclado, aditivos plásticos para mejorar la calidad, propiedades mecánicas del uso de plástico en el concreto, uso de BARRAS de FRP en el concreto, esto se ha hecho para conocer en qué medida es aplicable el uso de plásticos en el concreto, e incluso en qué procesos de construcción los estudios permiten un uso seguro, el uso de plásticos ha resultado en una ventaja.

Palabras clave: Hormigón, plástico, PET, FRP, propiedades mecánicas, métodos analíticos.

ABSTRACT

The use of plastics has been increasing since the industrial revolution where "It is estimated that close to 8,300 million metric tons (Mt) of virgin plastics have been produced to date" (Portilla Jiménez, J. G. (2022).) The large amount of plastics has allowed certain facilities for human beings, however, they put at risk the habitat where we develop as a species, not only because of the carbon emissions that are necessary to develop them, but also because they are not organic waste, these they cause great pollution as they are not biodegradable, "Plastics take about 180 years to degrade and are used in industries, in daily life they are products with a limited capacity for self-destruction, consequently, they remain for many years as waste." (López-Aguirre, J. F., Pomaquero-Yuquilema, J. C., & López-Salazar, J. L. (2020)), consequently, living in such a biodiverse country requires a change in the management of this waste, "The country that It must initiate its cultural change not only in the integral management of waste, but the policies aimed at production and import must be aligned with compliance with the principles of the Circular Economy and sustainable development." (Portilla Jiménez, J.G. (2022).)

"The results indicate that the citizens of the urban area of the Guayaquil canton have an environmental perception of 59.70%, environmental cognition of 41.92%, pro-environmental behavior of 76.50%, level of awareness of 60.68% and plastic single use that is most frequently used is the t-shirt-type plastic cover with 31.25%. Despite average cognition and environmental awareness, the citizens of the urban area of the Guayaquil canton are willing to participate and support strategies to minimize the consumption of single-use plastics." (Cobos Pazmiño, V. P. (2021)), the study carried out by Cobos Pazmiño shows a quite encouraging panorama, since there is an initiative to support strategies that minimize the consumption of plastics.

The purpose of the Present Integrator Project is to answer the question: What is known about the use of plastics in concrete?, where a series of sources were investigated according to the following word combinations: Use of recycled PET fibers in concrete, Types of Plastics used in concrete dosing, plastic fibers as additives, recycled plastic aggregate, plastic additives to improve quality, mechanical properties of the use of plastic in concrete, use of FRP BARS in concrete, this has been done in order to know in to what extent the use of plastics in concrete is applicable, and even in which construction processes studies allow safe use, the use of plastics has resulted in an advantage for humanity, however the problem of waste management has always existed , and this is where plastics affect the existence of the environment where human beings can survive, so considering the long period of time that plastic takes to decompose, several initiatives have emerged to eliminate this material, while dealing with recycling it, here comes the context of the use of this material in construction, where the disadvantage of plastic can be turned into an advantage, since the structures are developed with a relatively long design period, it is difficult to include materials whose average life is low This is why plastic, having a long half-life, allows it to be incorporated into the construction sector, where in Ecuador, being a country with such a biodiverse territory, where one of the economic sources that the country has is Tourism is about protecting these species, so the reuse of plastics would reduce the impact of these wastes on the environment that surrounds the country.

KEY WORDS: Concrete, plastics, PET, FRP, mechanical properties, analytical methods

TABLA DE CONTENIDO

DESARROLLO DEL TEMA

To obtain a robust search on the applications of plastics in concrete, at least 5 tabs were searched for each set of keywords used, where the keyword sets are: Use of recycled PET fibers in concrete, Types of plastics used in concrete mix design, Plastic fibers as additives, Addition of recycled plastic aggregate, Plastic additives to improve quality, Mechanical properties of plastic use in concrete, Use of FRP bars in concrete.

The combination of words was used in Google Scholar, and all articles in the 5 tabs were read, developed for each combination of words. To filter the information, inclusion and exclusion criteria were developed. To include articles, properties related to mechanical behavior in terms of flexural, compressive, and torsional strength were sought. The use of plastics in concrete for housing and non-road structures or in ports was also included, as well as articles related to concrete properties in the mix, such as slump, workability, and setting time. Computer analysis and methods to understand and predict the behavior of these types of mixtures were also considered. On the other hand, articles that incorporated variables were excluded because they did not allow for an understanding of the behavior of plastics alone in concrete. Articles that included fly ash, organic materials, radiation in plastics, and other additives were eliminated.

To have a search with updated information, the search was limited to a period of up to 5 years ago, except for articles of extreme importance.A total of 140 articles were included according to the established inclusion criteria, and a table was developed indicating the paper number, title, brief description, authors involved, and link to provide easy access. This allowed for the establishment of possible categories in which these articles can be grouped, enabling the analysis of mutual relevance.

When analyzing the results of the sources, 41 papers were obtained regarding the mechanical properties of concrete mixtures with the use of PET plastics, whose results were analyzed through laboratory tests. On the other hand, only 5 articles were found whose performance was analyzed either by numerical methods or computer assistance. At first glance, we can observe that in this part of the found studies, there is still a need for further development in this research sector.

PROPIEDADES MECÁNICAS MEDIDAS EXPERIMENTALMENTE (PET)

Flexural performance of layered PET fiber reinforced concrete beams.

The study used two percentages of PET fibers, 0.5% and 1% by volume, where the bending behavior of the manufactured beams was evaluated using PET fiber RC beams with three layers. This study compared these results with beams containing the same percentage of PET but using the full section. The chosen parameters for the sample testing were first cracking, yielding, and ultimate load, including the deflections associated with each load, allowing for the evaluation of failure modes, toughness, and ductility.

This showed a considerable improvement in terms of ultimate load capacity, and the load-deflection relationships showed a tendency for the stratified PET fiber concrete beams to exhibit a greater number of deflections before reaching failure. It was also found that the toughness capacity was doubled for the samples with 1% PET fibers.

(Ali, O., Al-Hadithi, A. I., & Noaman, A. T, 2022).

Stress-strain behavior of polyethylene terephthalate fiber-reinforced polymer-confined normal-, high- and ultra-high-strength concrete.

The study proposes a new stress-strain model oriented towards design based on a review of experimental data for concrete with different strengths, normal, high, and ultra-high, which is confined with PET FRP. The failure of the unconfined concrete batches occurs due to crushing failure, with an obvious shear plane and several inclined cracks, whereas it was found that in general the PFCC samples experience FRP rupture failures, thus, the failure occurs at the mid-height, while the FRP had a failure with a loud explosive sound. (Zeng, J., Ye, Y., Zeng, J., Smith, S. T., & Guo, Y, 2020).

Shear strength of a reinforced concrete beam by PET fiber.

Six strengthening beams were tested, which were designed to fail in shear, and were made with concrete containing various types of waste PET fibers, allowing for the study of direct shear strength. The results showed an improvement in the shear capacity of the beams using 1% PET plastics, with a 43.5% improvement in direct shear at 1.25% volume of PET fiber. Additionally, the study shows that adding PET fiber changes the mode of failure from shear to flexure, and the cracking and deformation characteristics are also modified due to the addition of fiber. Finally, equations have been proposed to calculate shear strength and direct shear (Ali, M. K., & Kh, T. ,2021).

The effect of concrete alkalinity on the behavior of reinforcing polyester and polypropylene fibers with similar properties.

The study evaluated three types of PET and PP fibers with similar mechanical and physical properties in terms of alkaline resistance in simulated alkaline hydrolysis environments.

Despite a significant weight loss of PET fibers in the initial stages of alkaline treatment, the rate of weight loss slowed down. However, the mechanical properties of PET fibers deteriorated due to the weight reduction phenomenon, while advantages were generated that improved the fiber-matrix adhesion properties. Thus, the test results demonstrated that PET fibers can be used as reinforcement in reinforced concrete and that fibers treated with alkaline hydrolysis can improve the mechanical properties of FRC. (Rostami, R., Zarrebini, M., Mandegari, M., Sanginabadi, K., Mostofinejad, D., & Abtahi, S. M, 2019).

Preparation and performance analysis of recycled PET fiber reinforced recycled foamed concrete.

This study focuses on evaluating the potential of transforming concrete waste and polyester fabric into an environmentally friendly product, recycled foamed concrete (RFC). The three variants of RFC were evaluated: unreinforced, reinforced with PET fiber, and reinforced with recycled PET fiber. The results indicated that the addition of recycled powder improves the compressive strength of foamed concrete, while the addition of PET fiber improves compressive strength and durability, without affecting dry density and water absorption.

Thus, it is concluded that recycled PET fiber had a better improvement effect than conventional PET fiber. The RFC reinforced with recycled PET fiber showed a higher dry density and compressive strength by 5.2% and 5.1%, respectively, compared to the RFC reinforced with conventional PET fiber, which showed a 10.7% lower water absorption. (Tang, R., Wei, Q., Zhang, K., Jiang, S., Shen, Z., Zhang, Y., & Chow, C. W, 2022).

Mechanical Optimization of Concrete with Recycled PET Fibres Based on a Statistical-Experimental Study

The aim of the study is to evaluate the use of recycled PET fibers in concrete to reduce waste and improve the material's mechanical strength.

The quantity and aspect ratio of the fibers were studied in 120 samples, evaluating the compressive, flexural, and tensile strength. It was concluded that the quantity of fiber has a greater effect on strength than the aspect ratio, and that concrete reinforced with recycled PET fibers performs better than control samples, like virgin fibers. This gives us indications that there could be a positive impact on the conservation of marine fauna and soil fertility, as well as reducing waste on a global level. (Meza, A. B., Pujadas, P., Meza, L. J., Pardo-Bosch, F., & Lopez-Carreno, R. D, 2021).

Effects of recycled PET fibers on the mechanical properties and seawater curing of Portland cement-based concretes

The paper deals with the use of PET waste and its applications as a partial substitute for aggregate, and even as reinforcement for concrete, finding that one of its main limitations is the hydrolysis processes in the PET ester bonds, where to prevent alkaline hydrolysis, PET fibers were coated with an ethylene/vinyl acetate (EVA) copolymer. Demonstrating the effectiveness of using the EVA copolymer as a protective layer against strong alkaline solutions. At the same time, how the properties of compressive and flexural strength, and long-term durability performance were affected by the addition of recycled PET fibers in an alkaline environment was investigated, finding that their initial observations show that the introduction of PET fibers does not deteriorate the mechanical strength of the concrete composite. (Wiliński, D, 2016).

Anisotropy and bond behavior of recycled Polyethylene terephthalate (PET) fiber as concrete reinforcement

The present study analyzed the behavior of adherence of recycled PET and anisotropy under different conditions. Three tests were conducted, which showed that the anisotropy in tensile capacity changed when producing PET at different angles. Additionally, it was discovered that inserting fibers up to 5 mm resulted in superior interfacial bonding performance and bond strength equivalent to samples with 17.5 to 30 mm fibers. The results indicate that the flexural strength was similar in samples reinforced with recycled PET, regardless of fiber length, with a 7% variation in residual strength. Finally, 104 and 63 recycled PET fibers will be needed to withstand the flexural load and sustain the drop in flexural load capacity after the peak, respectively, which is related to the number of fibers located in the cracking zone. (De Luna, A. M., & Shaikh, F. U. A, 2020).

Performance of Concrete Using Light Waste PET Fiber

This document reviewed studies on the performance of concrete with PET waste content. For the incorporation of these waste materials, they were added using a binder such as fly ash. Due to the reduced friction between cement and aggregates due to the spherical shape of fly ash, increased workability and flow of fresh concrete were obtained. Incorporating these plastic waste materials in the form of fibers for structures makes it an economically attractive option. As the use of lightweight plastics in fresh mixes becomes more popular over the years, research on this topic will become more relevant, providing more technical knowledge and establishing a designation for the use of waste materials. (Irwan, J., Faisal, S., Othman, N., Wan, I. M. H., Asyraf, R., & Annas, M, 2013).

Concrete Incorporated with Optimum Percentages of Recycled Polyethylene Terephthalate (PET) Bottle Fiber

For this study, the laboratory results were analyzed, where the percentage of recycled PET fibers in the concrete was controlled during curing times of 7 and 28 days. In the tests, the properties of both fresh and hardened concrete were evaluated, considering workability, compressive strength, and tensile strength. It was observed that increasing the content of PET in the concrete mix leads to a decrease in workability due to the increased friction between the particles, as the plastics absorb the cement paste, reducing its plasticity and consistency. The results are presented in a table, and a figure shows the decrease in concrete workability as the amount of PET fibers increases.

Recycling woven plastic sack waste and PET bottle waste as fiber in recycled aggregate concrete: An experimental study

The mechanical properties and durability of recycled aggregate concrete (RAC) reinforced with various types of fibers, such as recycled plastic fiber (RWS), recycled polyethylene terephthalate (RPET) fiber, and steel fiber (SF), were examined. The results show that the proposed mixing technique and the addition of SF improve the properties of RAC with 100% recycled coarse aggregate. They are also capable of remedying the loss of compressive strength caused by the recycled plastic fiber. The use of RPET and RWS fibers was found to improve the post-cracking properties, shear strength, and splitting tensile strength of RAC, while decreasing its density. It is possible to mention that the use of recycled plastic fibers in RAC can significantly contribute to the sustainable development of the construction industry. However, further research is necessary to investigate the drying shrinkage, long-term performance, and cost-benefit analysis of RAC samples containing PET and RWS fibers, as well as the behavior of pavement structures under dynamic loading and environmental impacts. Pavement structures are recommended for the use of these materials (Bui, N. H., Satomi, T., & Takahashi, H, 2018).

Mechanical properties and impact behavior of PET fiber reinforced self-compacting concrete (SCC)

According to the study, successful laboratory production of SCC (Self-Compacting Concrete) containing PET fibers is possible despite a decrease in fresh properties. The use of PET fibers reduces values of slump flow and T50 measured, with the lowest values for a concentration of 2% PET fibers. Studies showed an increase in flow time in V-funnel for all mixes containing PET fibers. On the other hand, in terms of mechanical properties, it was demonstrated that adding PET fibers in different volumes improved the compressive strength, flexural strength, and modulus of elasticity of SCC. The optimum content of PET fibers for SCC was determined to be 1.5%, however, moderate to high concentration of PET fibers (between 1% and 1.5%) can be accepted to prevent further decrease in workability and improve SCC properties. Overall, it was demonstrated that the impact strength of SCC plates was significantly improved due to the addition of PET fibers, showing an improvement in the SCC's energy absorption capacity. Additionally, a transition from brittle to ductile failure mode of SCC plates was determined due to the bridging action of PET fibers between the broken parts of the concrete plate. (Al-Hadithi, A. I., Noaman, A. T., & Mosleh, W. K, 2019).

Effects of PET fiber arrangement and dimensions on mechanical properties of concrete

The study showed that adding 1.0% PET fiber to concrete compromises its tensile strength but improves its ability to absorb energy in the post-cracking state due to the bridging effect of the fibers at the time of cracking. On the other hand, in terms of flexural strength, the study reflects that adding 0.5% PET fiber increases the flexural strength of concrete depending on the geometry and dimensions of the fibers. In this way, it was determined that dispersed short fibers offer greater energy dissipation capacity, while flat fibers with a cut end reflect a much greater capacity than straight-ended fibers. However, the structure with a 1.0% fiber content increases its porosity and presents a decline in ultrasound velocity due to its lower workability. Finally, a fiber concentration of 0.5% is considered acceptable according to standard norms. (Marthong, C, 2015).

Hardened properties of binary cement concrete with recycled PET bottle fiber: An experimental study

For the present study, it was found that the addition of recycled PET bottle fibers in binary cement concrete mixes reduces the slump, achieving a slump between 97 and 80 mm for the remaining concrete mixes. For mix 4FRBC, which contains 0.4% fiber and 10% MK, there is a 10.67% increase in compressive strength and an 84.6% increase in tensile strength. In terms of flexural strength, an improvement is observed for the same mix, concluding that the optimal level of fiber addition is 0.4%. Higher fiber percentages do not improve the strength or modulus of elasticity of the concrete. Further research is needed to determine if the use of PET bottle fibers enhances the durability and performance of the mixes, as they are an excellent option for the construction industry. (Thomas, L. S., & Moosvi, S. K, 2020).

Flexural performance of layered PET fiber reinforced concrete beams.

The study evaluates the use of polyethylene terephthalate (PET) fibers produced from waste plastic bottles, which were used in reinforced concrete (RC) beams. PET fibers were included in concrete in two percentages of 0.5% and 1% by volume to evaluate the influence of layer distributions of fibers on the flexural behavior of the beams. The use of 0.5% of fibers showed an increase in mechanical properties such as strength, compression, and elastic modulus. On the other hand, the increase in these fibers shows a tendency to decrease these properties. (Ali, O., Al-Hadithi, A. I., & Noaman, A. T, 2022)

Influence of PET fiber geometry on the mechanical properties of concrete: an experimental investigation

This paper presents a comparative analysis to investigate the influence of different fiber geometries on the mechanical behavior and physical properties of concrete using PET fibers. The workability with PET fibers decreases by more than 25%, but an addition of 5% represents an improvement in compressive strength of the samples, which varies depending on the fiber geometry. The samples without fibers exhibited brittle failures, while the addition of PET fibers improved crack bridging properties.

In terms of tensile strength tests, the addition of 5% PET improves this capacity, and an increase in flexural strength is also observed. The load vs. displacement curves shows a ductile behavior, which also varies depending on the fiber geometry. The flatended slit sheet geometry shows a significant improvement over straight slit fibers in terms of load capacity and energy dissipation. (Marthong, C., & Sarma, D. P,2016).

Strength behavior of reinforced concrete beam using re-cycle of PET wastes as synthetic fibers

The paper aims to evaluate the mechanical properties of normal concrete containing residual PET fibers, as well as to analyze the influence of these residues on the behavior of designed beams. Five samples were tested with a water-to-cement ratio of 0.41, and the results showed that workability decreased with an increase in PET fibers. Furthermore, the incorporation of PET fibers showed a decrease in flexural strength while improving compressive strength, and the samples met the increased compressive strength except for the mixture with 3% PET fibers. However, the mixture containing 1.5% fibers was the only one showing an improvement in flexural strength.

The results indicated a decrease in maximum load by the beams, but although there was a slight decrease in this capacity, the fibers showed a positive effect on ductility, which was 2 to 5 times that of the reference beam. (Adnan, H. M., & Dawood, A. O, 2020).

Effect of Fiber Parameters on the Strength Properties of Concrete Reinforced with PET Waste Fibers

The paper presents a comparative experimental study of reinforced concrete with steel fiber and PET fiber, aiming to highlight the effects of PET fiber on the mechanical properties of concrete. The results show that the performance with steel fiber is not comparable to that shown by PET fiber in terms of compressive strength, modulus of rupture, and tensile strength. In general, there is a loss of strength with PET fiber, but it is possible to reduce these losses by using thicker PET fibers.

For concrete with 20mm fiber, there is a reduction in compressive strength, but it is not significant according to the t-test analysis. However, for 35mm and 50mm, there are significant losses, while the mixture with 20mm shows a significant increase in tensile strength by shear. (Mohammed, A., & Mohammed, I. I, 2021).

Flexural behavior and analysis of reinforced concrete beams made of recycled PET waste concrete.

The paper studies the behavior of reinforced concrete beams containing crushed particles of PET waste. It was found that the control in the classification of the particles does not allow for controlling the loss of compressive strength, where a significant reduction in the strength value was observed even with a low percentage of PET waste, reaching 5%. On the other hand, there was no further reduction in strength when the percentage of waste was increased by 15%.

Many specimens were observed to suffer a high reduction in strength, which contained a volume of PET waste not exceeding 10%. It was found that properties related to the modulus of rigidity and mode of failure are not affected using these waste materials. However, the ultimate load-carrying capacity is moderately reduced by 14.9% when the content of PET waste is 15%. The study indicates a good possibility of using the simple analytical model for under-reinforced concrete beams provided by the ACI 318 code to predict the ultimate moment capacity of PET waste. (Mohammed, A, 2017).

Preliminary analysis of concrete reinforced with waste bottles PET fibers.

The article analyzes and discusses the preliminary results on concrete reinforced with PET fibers, where the research focuses on the use of widely available waste material such as PET. The fibers were obtained by simple cuts on the bottles, which were not exposed to any processing, reducing FRC production costs.

It was found that the addition of small amounts of PET fibers has a great influence on the post-cracking behavior of concrete elements, where lamellar fibers such as "O"-shaped fibers greatly improved the toughness of the samples. The improvement in toughness is more pronounced for "O"-shaped fibers, where their shape seems to help bond the concrete on each side of the cracked section. Tests also show a tendency for PET fibers to increase ductility in concrete, for which further research will attempt to add superplasticizers to the sample (Foti, D, 2011)

Early age performance and mechanical characteristics of recycled PET fibre reinforced concrete

The aim of this article is to investigate the use of PET fibers in concrete and how their addition affects the mechanical properties of the material and its performance at early ages. Nine mixtures were analyzed using two different fiber profiles, which were used in three volume percentages and two different fiber lengths.

It was concluded that the addition of PET fibers reduces the compressive strength from 0.5% to 8.5% when compared to the control sample. A greater reduction was experienced as the volume fractions increased, while the samples with shorter fibers performed slightly better than those with longer fibers. Regarding the results of the flexural tests, it was shown that the concretes containing fibers achieved a higher peak load than the control mixture, maintaining a similar linear elastic behavior until failure. However, the residual strength after cracking depends on the fiber percentage, where samples with a higher percentage indicated better residual strength. (Borg, R. P., Baldacchino, O., & De Belie, N, 2016).

The effect of using polyethylene terephthalate as an additive on the flexural and compressive strength of concrete

The study shows the behavior of concrete when subjected to the addition of PET fibers, where a decrease in workability is shown, which increases as the PET content increases. The samples indicated optimal compressive strength at 28 days of curing compared to the control concrete, which was made with a 5% PET by weight, showing a progressive decrease in flexural strength as the percentage of PET in the concrete increases. Therefore, it is indicated that the application of concrete with PET can be recommended due to its higher compressive strength, which reaches a value of 33.4 N/mm2. (Umasabor, R. I., & Daniel, S, 2020).

Assessment of mechanical properties and workability for polyethylene terephthalate fiber reinforced concrete

The article analyzes the mechanical behavior of concrete when exposed to PET in its mixture, where due to the resistance of the fibers to movement, the slump and compaction tests indicate a decrease in workability. In terms of dry density, this property decreases, however, it manages to reduce the dead weight of concrete. Finally, an increase in compressive strength is evident in both cylindrical and cubical samples. (Meena, A., Surendranath, A., & Ramana, P, 2021).

Physical and mechanical properties of concrete containing PET wastes as a partial replacement for fine aggregates

The article studies the behavior of the mechanical properties of concrete containing PET as a partial replacement for fine aggregates, leading to a reduction in the workability of the mix, where the settlements decrease by 12.5% and 62% for replacements of 5% and 20%, respectively. An increase in the absorption rate was also evident with a higher percentage of 20%, while the compressive and indirect tensile strengths increase as a function of the percentage increase of PET, reaching up to 12% of the volume, where an optimal percentage of 7.5% is found, resulting in increases of 43.64%, 26.9%, and 30.2% for compressive strength, indirect tensile strength, and flexural strength, respectively. (Dawood, A. O., Al-Khazraji, H., & Falih, R. S., 2021).

Properties of eco-friendly pervious concrete containing polystyrene aggregates reinforced with waste PET fibers.

The article shows how the addition of EPS aggregates and PET fibers improves flexural strength, maintaining that the optimal percentage of PET fibers is 1%, since a higher content does not result in benefits, as at higher concentrations, the flexural strength is compromised. There was a systematic reduction in compressive strength, despite this, the range of results is within acceptable ranges for the applications of permeable concrete (Ali, T. K. M., Hilal, N., Faraj, R. H., & Al-Hadithi, A. I, 2020).

Eco-friendly concrete containing recycled plastic as partial replacement for sand

The article analyzed the possibility of using PET in concrete and how it affects its mechanical properties, where it was observed that the use of PET fibers reduces the weight of the material, however, the study highlights that the mechanical properties of concrete were affected by increasing the proportion of PET. (Almeshal, I., Tayeh, B. A., Alyousef, R., Alabduljabbar, H., & Mohamed, A. M, 2020).

PROPIEDADES MECÁNICAS MEDIDAS POR SIMULACION U ANÁLISIS NUMÉRICO

Application of Machine Learning to Predict the Mechanical Characteristics of Concrete Containing Recycled Plastic-Based Materials

The article analyzes the possibility of using neural networks to predict the mechanical properties of concrete with PET, where results were obtained with a MSE error of 7.11 MPa and a correlation coefficient of 98%. The results of the neural network showed that the addition of PET has an adverse impact on the compressive strength of concrete, and this impact is more present in larger amounts of PET fibers. Additionally, the shapes of PET fibers influence compressive strength, where this effect depends on the bond strength between fibers and the concrete matrix. The study also found that the tensile strength of PET fibers plays a dominant role with greater bond strength, while the modulus of elasticity tends to affect compressive strength. (Rezvan, S., Moradi, M. J., Kheyroddin, A., Daneshvar, K., Karakouzian, M., & Farhangi, V., 2023)

Mathematical model valuation for recycled material mechanical strengths

The article aims to develop constitutive models and relationships to achieve effective modeling that meets specific standards for concrete with different percentages, demonstrating how numerical methods proved to be quite accurate, since simulations indicate that as the proportions of PET waste increase, the factors of compression, tension, and traction resistance decrease. (Meena, A., & Ramana, P, 2022)

Effect of partial replacement of sand by plastic waste on impact resistance of concrete: experiment and simulation

The article experimentally and analytically studies the behavior of concrete with the addition of PET plastics, where various volume percentages of plastics were used ranging from 5% up to 20%. Experimentally, it was found that the strength decreased with increasing plastic content, where the average compressive stress is reduced by 24% when 20% of the volume is replaced by plastics. The maximum static flexural load is also affected, however, the flexural energy of the concrete with 20% plastics is higher than that of the concrete without additives by 198%.

Afterwards, it was demonstrated that a simulation model using finite element analysis with the use of LUSAS can effectively predict load vs. displacement behavior for both plain concrete and those with percentages of PET plastics, providing realistic and accurate predictions. (Mustafa, M., Hanafi, I., Mahmoud, R., & Tayeh, B. A, 2019).

Response of hybrid concrete incorporating eco-friendly waste PET fiber: Experimental and analytical investigations

The study analytically predicts the ultimate load capacity for beams that had PET fibers included, where the ultimate load is calculated by modifying the methods given by ACI such as ACI [60] and Jarquio [61]. The effect of comparing the analytical and experimental study showed that these results align, allowing the use of analytical methods to understand the mechanical behavior of this type of concrete. (bdullah, Q. M., & Haido, J. H, 2022).

PROPIEDADES MECÁNICAS MEDIDAS EXPERIMENTALMENTE (FRP)

Use of recycled fibers in concrete composites: A systematic comprehensive review

The study analyzes the behavior of FRP, ECR, and FSR in the mechanical behavior of concrete, where it is found that the shape and texture of the fibers have an undeniable influence on the fresh and mechanical properties of concrete, indicating that there can be a slight increase in compressive strength when optimal percentages are added, while tensile and flexural strength show a significant improvement. This study also analyzes the possibility of using empirical methods, indicating their importance when predicting the mechanical behaviors of concrete, where it finds that the strength of these models is that they can be evaluated based on their R-squared values. (Ahmed, H. U., Faraj, R. H., Hilal, N., Mohammed, A., & Sherwani, A. F. H, 2021).

Mechanical Strength Characterization of Plastic Fiber Reinforced Cement Concrete Composites

The article used plastic waste fibers, which were uniformly distributed in the cross-section while using confined plastic fibers in the tension zones. Subsequently, compression and flexural tests were carried out, where it was found that the stress-strain of the samples incorporated with 0.15% volume showed a significant improvement in compressive strength, reaching its highest value at 33.20 N/mm2, while its peak post-compression toughness was 357.75 N-mm. On the other hand, the failure modes were controlled with multiple visible cracks on the surface.

The flexural evaluations showed that the mixes incorporated with plastic fibers can be beneficial, highlighting that the effective fibers are those placed in the tension zone, thus contributing to a maximum toughness of 33.43 mm and a maximum residual strength of 4.37 N/mm2, giving us an optimal volume of fibers at 0.1% of the volume, where there is a maximum flexural strength of 5.26 N/mm2. (Anandan, S., & Alsubih, M, 2021).

Compressive Strength Testing of Hybrid Concrete-Filled Fiber-Reinforced Plastic Tubes Confined by Filament Winding

The study analyzes the mechanical behavior of FRP hybrids, where the results of the compressive strength of PFRP-FFRP indicate that the performance in terms of compression is improved as the thickness of FFRP increases. It was found that compressive strength is benefited by increasing the confinement pressure, when it was 3.5 MPa, also observing a reduction in strength when the standard design was 30 MPa or higher. The experimental results indicated that the thickness of FFRP decreases along a defined dimension, while the compressive strength of the CFFT hybrid is determined by the confinement pressure according to the thickness of FFRP and the design strength of the concrete. (Kang, I., & Kim, S. Y, 2021).

Performance of plastic wastes in fiber-reinforced concrete beams

The study confirms that adding RPET or RPET-10 fibers to reinforced concrete samples does not decrease their deflection behavior, where it is shown that beams containing RPET-10 improve the strength of the first crack by 32.3%. However, the maximum load results of the samples containing RPET fibers are insignificant compared to normal reinforced concrete beams. Nevertheless, RPET fibers produced significant results, especially in the linear elastic region. (Khalid, F. S., Irwan, J., Khan, I. A., Othman, N., & Shahidan, S, 2018).

A comparison between the use of FRP, FRCM and HPM for concrete confinement

The article shows the effect of confinement using FRP, FRCM, and HPM, which were evaluated in uniaxial compression tests. It was found that composite systems are effective in increasing the compressive strength and ductility of elements. It should be noted that the final performance and failure modes show differences, with FRCM systems being less effective than FRP in confining concrete. The maximum strength was 30% lower when coupled with an epoxy resin and 17% lower when using PBO fabrics. In the case of concrete cylinders confined with FRP, failures were observed due to fiber rupture, which is dependent on the different capacity of organic (FRP) and inorganic (FRCM) matrices. The DT200 and ACI 549 models provide reliable predictions for the response of elements confined by FRP and FRCM. (Donnini, J., Spagnuolo, S., & Corinaldesi, V,2019).

A state-of-the-art review: Near-surface mounted FRP composites for reinforced concrete structures

The study results in a review of several articles that analyze the mechanical properties of using FRP and its potential application. They find that the mechanical behavior of FRP composite materials depends on the properties of the matrix, thus affecting the tensile strength and ultimate deformation, adhesion strength, and modulus of elasticity. Members reinforced with NSM-FRP indicate better performance and service while exposed to monotonic loads, with FRPs reducing the stress received by steel bars, which extends fatigue life. It is noteworthy that in most cases, service requirements dominate the design, highlighting the lack of standards and codes, since most focus on EB-FRP systems. (Al-Saadi, N. T. K., Mohammed, A., Al-Mahaidi, R., & Sanjayan, J. ,2019).

Behavior of FRP-confined FRP spiral reinforced concrete square columns (FCFRCs) under axial compression

The study shows how confinement with fiber-reinforced polymer (FRP) is efficient in improving the deformations and resistance capacity of concrete, while concrete confined with PET FRP exhibits a softening deformation behavior. The study proposes new square columns using PET FRP with FRP spirals, utilizing the benefits of spiral reinforcement. The axial compression behavior shows a softening deformation behavior of confined concrete, which is avoided after the first peak, achieving hardening behavior, especially when using a 30 mm spiral. (Zhou, J., Lin, W., Guo, S., Zeng, J., & Bai, Y, 2022).

PROPIEDADES MECÁNICAS OBTENIDAS ANALÍTICAMENTE (FRP)

Investigation of the compressive behavior and failure modes of unconfined and FRP-confined concrete using digital image correlation

For the following paper, a total of 10 specimens were tested with different instrumentation to measure the different types of strains using digital image correlation. The idea was to develop axial, lateral and Von Mises strains in the unconfined and confined FRP concrete specimens under axial compression. The methodology included non-contact and contact methos to see the correlation between macro responses and localized deformations. For the contact method, linear variable displacement transformers were used and for the non- contact method, strain gauges were used for digital image correlation.

The outcome of the results showed that deformations are more localized in unconfined specimens while strains distributed homogenously in confined specimens.

Also, on confined FRP specimens, a larger lateral stiffness led to a more homogenous distribution of cracks and strains in the specimen, but a weaker confinement shows more localized deformations. In the other hand, for the Von Mises strain, the maximum effect occurred on the mid height for FRP confined specimens while for unconfined specimens, the maximum effect occurred on the upper region of it. The goal behind this paper showed that there is a way to correlate DIC and under axial compression behavior without the correlation of strain and position, so it is easier to view the development of strain during deformation. (Pour, A. N., Nguyen, G. D., Vincent, T. L., & Yaseen, Z. M., 2020).

Data-driven analysis on ultimate axial strain of FRP-confined concrete cylinders based on explicit and implicit algorithms.

The following paper analyzes the ultimate strain of FRP confined cylinders derived from regression analyses on small databases. The methodology used Bayesian probabilistic and machine learning prediction models with high accuracy. Initially, a database containing 471 test results about the conditions for FRP confined concrete cylinders were collected from open literature. Later, by using the Bayesian probabilistic technique, all models were evaluated to look for the critical parameters and refine them. Studies showed that these models achieved great predictive performance to use FRP confined concrete columns in different construction applications.

Along the paper, it is determined that the material geometry, strength properties, strain properties, FRP properties and confinement properties were the most crucial parameters to determine the ultimate axial strain. It is said that the theorical calculation for the ultimate strain is wrong due to large scatter and omission of critical parameters. The use of back programming artificial neural network, multi gen genetic programming and support vector machine were used to develop three ML models to predict the ultimate axial strain. These predictions considered no relation between independent and dependent variables. Furthermore, the use of SVM algorithm performs better simulations for the critical mechanical properties of FRP confined concrete cylinders so it can be designed and evaluated. (Chen, W., Xu, J., Dong, M., Yu, Y., Elchalakani, M., & Zhang, F., 2021).

Prediction of Properties of FRP-Confined Concrete Cylinders Based on Artificial Neural Networks

The following paper describes the use of FRP confined concrete cylinders. It is known that the use of these materials increases strength and ductility leading to more extensive research using artificial neural network methods. Initially, the paper proposes the study of 708 specimens for strength and 572 for strain from previous experiments while using two techniques. The first method employs the use of ANNs and the second one uses general regression analyses, both techniques used to study axial strength and strain. As a result of the study, it was established that the use of ANNs can predict the axial behavior of FRP confined concrete specimens with high accuracy being a useful tool for analyze and design of compression members. The predictions of ANN and analytical models outperformed the empirical methods while these only consider trivial computation to provide outputs. (Ahmad, A., Plevris, V., & Khan, Q. M, 2020).

A Review of Fiber Reinforced Polymer (FRP) Reinforced Concrete Composite Column Members Modelling and Analysis Techniques

The following paper describes the benefits of FRP confined concrete columns as an improvement on its strength and ductility. The way that improvement is made is by reducing lateral passive confinement.

CONCLUSIONS

There are experimental and analytical models that demonstrate that the use of these plastics does reflect an improvement in the mechanical properties of concrete, considering certain plastic concentrations, being 0.5% to 1% for PET and 0.15% for FRP. The use of plastics in concrete shows great development in terms of PET research, since there are many papers for this case, however, only 4 of them obtained results through analytical methods and allowed them to be contrasted with experimental data. There are experimental and analytical models that demonstrate that the use of these plastics does reflect an improvement in the mechanical properties of concrete, considering certain plastic concentrations, being 0.5% to 1% for PET and 0.15% for FRP.

The feasibility of these analytical methods to predict the mechanical behavior of plastic use in concrete to optimize time and resources was found to be promising, as correlation percentages of 98% were obtained along with an error of 5% for PET and 17% for FRP. It is suggested to investigate more about analytical methods, since these methods mainly focus on plastic percentages, and here they omit the possibilities of mechanical behavior according to the geometry of PET, where there is a large amount of experimental research for that case.

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