Environmental use of waste materials as admixtures in concrete

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Abstract. Humanity, from prehistoric times, influences the environment in which it lives. Often these are unfortunate negative influences. One of such negative effects is the accumulation of waste. We are an animal species that has always left a lot of waste, food remnants, various tools, remnants of producing these tools, and much more. First, the mankind used resources from which the waste was minimal and which was moreover degradable. As a result of the development of the company, the need for better, more perfect products developed and hand in hand is associated with more waste and non-decomposable or non-decomposable waste. The more humanity is at the higher level of development, the more waste it produces. However, this behavior conflicts with the sustainability of the environment. Fortunately, they are making bigger efforts to recycle the waste, ie re-use of waste materials. Construction is not behind this, and many efforts are being made to use the waste materials in building structures. The best known is the recycling of glass for the production of window glass, for example, but there are many examples. Glass has exceptional properties in this respect because it can be recycled to the infinity. For many substances, it is not possible to find a use other than their primary use. In this article, we are focusing on the re-use of various waste materials as admixtures in concrete. The use of waste materials in concrete is directly available, not only because of the number of concrete structures, but also because of the closure of waste materials in its structure. Some waste materials can be used as fillers, that is to say, substitute aggregates, but they are substances which can also be used as a replacement for a part of a binder, in this case, of cement. The article summarizes the existing use of waste materials in concrete and provides a space for possible detailed research on this concrete.

1. Introduction
The aim of this work is to summarize and compare existing knowledge about the use of plastic waste as an admixture to concrete. In this work, we will deal with the physical properties of such concretes and their utilization in the building industry.

Nowadays, concrete is the most widely used material used for construction. As consumption increases, the cost of manufacturing increases as well as the natural raw materials from which the concrete is produced. For this reason, there is an effort to find alternative products to replace natural raw materials used for concrete production. As we produce a great amount of waste as humanity, which cannot be disposed of quickly and efficiently, there are efforts to exploit these wastes as an alternative to natural resources, for example, the replacement of natural aggregate with plastic waste in various forms, or the replacement of raw materials used for cement production.
2. Summary of research results to date

Many publications deal with the issue of the usability of plastics as a concrete additive, for example, Azad A. Mohammed et al. [1]. The article describes the properties of fresh concrete and hardened concrete with partial replacement of plastics. It is a replacement with plastic granules or plastic powder. Samples with different plastic fractions were tested, with the use of a certain fraction changing the other properties of the fresh concrete mix or the hardened concrete. When replacing up to 30% of aggregate with PVC foil from PET bottles, there was no significant change in concrete strength. When replacing 30% of the coarse aggregate with a plastic aggregate, there was a decrease of only 7.4% of the compressive strength to approximately 38.45 MPa compared to a sample without a plastic aggregate of 41.51 MPa. When replacing not more than 45% fine aggregate and 30% coarse aggregate with PVC aggregate, workability is not impaired. At higher percentages, worse workability of the concrete mixture was observed [1].

An article dealing with plastics, such as concrete additive, by Yuzhi Chen, Lingyu Xu, Weihong Xuan, Zan Zhou, [2] is dealing with the use of HDPE plastic, which is one of the most widely used plastics in the world. Based on the tests, it has been found that although the resulting tensile strength decreases with the increasing proportion of plastic granules, the addition of plastic granules resulted in better formability of the concrete mixture [2].

L. Gu, T. Ozbakkaloglu [3] describes the different types of plastics and their influence on the resulting properties of the concrete produced. The plastics used for recycling were divided into PA (Plastic Aggregates) and PF (Plastic Fibers), both recycled by direct mechanical recycling or melting. When comparing these two methods, worse mechanical properties of concretes were found which contained plastic particles recovered by mechanical recycling compared to melt recycling. Concrete containing PA and PF showed a smaller decrease in cone settlement test compared to the traditional concrete mix. With the addition of plastic aggregates or plastic fibers, it becomes more difficult to handle the concrete mixture. When using plastic aggregates with a low modulus of elasticity, there was a significant deterioration of the concrete properties compared to the use of high modulus plastic aggregates. Concrete containing plastic fibers achieves a higher compressive strength and tensile bending strength of about 10% with a plastic fiber content of up to 1%. At 1.5% of the plastic fiber content, the compressive strength decreased. An important aspect that affects the resulting strength is the ratio of fiber length to fiber diameter. Fibers with a ratio of 20, 40, 60, 80 were tested, while the compressive strength increased from 5%, 8%, 14%, 3%. On the other hand, by using the 100 ratio, there was a decrease of 6% [3].

Araghi et al. [4] carried out research in 2015, in which ground PET particles of a maximum size of 7 mm were used, with a unit weight of 464 kg / m3 and a specific gravity of 1.11 g / cm3, to replace natural aggregates. The aggregate was replaced by 5%, 10% and 15% of the plastic aggregate. The research found that the addition of plastic aggregates reduced the compressive strength of concrete. However, the resistance of the concrete to the aggressive environment has increased; in particular, the concrete has been exposed to 5% sulfuric acid for 60 days, where it has improved properties compared to an ordinary sample. Samples with 15% PET aggregate show the lowest weight loss and better resistance to sulfuric acid attack [4].

In 2014, Saikia and Brito [5] conduct research to investigate the properties of concrete with the addition of finely cut flaky particles, coarse-cut flake particles, and heat-treated pellet-shaped pellets. Natural aggregates have been replaced by each of these types of plastic particles. Samples from 5%, 10% and 15% of the plastic particles were tested. When testing finely cut and coarse-cut flocculent particles, worse performance properties of the concrete mix were found. For better workability, it is necessary to increase the water coefficient. By using pellets in the shape of balls, it is possible to reduce the water coefficient. As the percentage of plastic aggregates in the concrete mixture increases,
the density of the concrete decreases. This is mainly due to the low bulk density of plastics compared to natural aggregates. All types of aggregate have a low modulus of elasticity compared to the reference concrete. This decreases with increasing content of PET aggregate in the concrete mixture. Differences in the size of added aggregates result in varying properties of the fresh concrete mixture. When the concrete was hardened, better abrasion properties were observed when adding PET aggregate to the reference concrete. When adding round smooth (PP) aggregate to the concrete mixture, better results were observed with its increasing proportion. For fine particles (PF) and coarse particles (PC), the best results were found for 10% PF and PC aggregate in concrete [5].

Similar research was carried out in 2013 by Rahmani et al., [6] Replacing ground PET particles with a maximum size of 7 mm with a unit weight of 464 kg/m³ and a specific gravity of 1.11 g/cm³ of sand in the concrete mixture. The replacement was 5%, 10% and 15% of the plastic aggregate. Replacement of 5% resulted in increased compressive strength. When replacing 10%, the compressive strength was approximately the same as for concrete without PET aggregate, but the concrete had a lower modulus of elasticity. Based on this, concrete with better ductility can be obtained with PET particles [6].

In 2012, Ramadevi and Manju [7] tested the replacement of fine aggregates with 1%, 2%, 4% and 6% PET fibers. The research results show the highest increase in compressive strength, tensile strength and breaking strength when replacing fine aggregates with PET aggregates up to 2% and approximately 40 MPa compared to the reference sample (approximately 31 MPa). At 4% and 6% substitutions, the strength decreased, but the strength was still higher than for samples without PET aggregates. Therefore, it is recommended to work with samples containing 2% PET aggregates for further research [7].

Bhogayata et. al. [8-10] used as an aggregate in concrete metalized polyethylene garbage bags that were added to the concrete as fibers with an average size of 1-2 mm by 0.5%, 1% and 1.5%. The results of these tests have shown that the addition of these aggregates to the concrete mixture in an amount of 0.5% to 1% resulted in a negligible reduction in compressive strength. The most suitable water coefficient for such a concrete mixture was 0.45, which provided good workability [8]. In previous research, he also dealt with polyethylene when he added 60 mm x 3 mm polyethylene fibers in ratios from 0.3% to 1.2% by volume to concrete in his 2012 research. Here he concluded that plastic bags could be used in shredded form up to 0.6% in concrete to ensure good workability of the concrete mix. The macrofibers that have been hand cut are not suitable for being added to the concrete mix. Adding such fibers above 0.6% of the concrete volume reduced the strength by about 30% over the reference sample. Subsequent addition to 1.2% of the concrete volume reduced the strength by 50% compared to the reference concrete [9], [10].

High density polyethylene (HDPE), or high density polyethylene, is dedicated to Malagaveli [11] in 2011. The fibers made from HDPE were added from 0% to 6% to the concrete mix. The strength of the concrete was increased by using HDPE fibers at a maximum of 2% [11].

The problem of recycling plastic waste was dealt with by Prahallada and Parkash [12] in 2013. In their publication, they test plastic fiber concretes obtained by cutting plastic dishes with different aspect ratios of 30, 50, 70, 90, 110. These fibers were added to the concrete mixture with a bulk of 0.5%. Based on the tests carried out, where compressive, tensile, flexural and impact strength were measured, the best results were found for plastic fibers with an aspect ratio of 50. Compressive strength increased by 11% to 30.15 MPa, up to 13% to 3.2 MPa. The flexural strength was increased by 10% to 6.23 MPa and the impact strength was increased by 110% to 207.65 Nm. All plastic strengths have already dropped in plastic fiber tests with an aspect ratio over 50 [12].
Suganthy et al., [13] 2013, in its publication tested crushed plastic added to the concrete mix in the form of 1 mm granules. Sand in the concrete mixture was replaced by 25, 50, 75 and 100% plastic granules. It has been found that with increasing sand replacement by a plastic aggregate, it is necessary to increase the water coefficient to maintain the processability of the concrete mixture. With increasing plastic particles, the weight of the test specimens decreased, which is due to the lower bulk density of the plastics compared to the sand. The strength of the concrete when replacing up to 25% of sand has been gradually reduced, but has dropped significantly when replacing 25% or more. At 25% replacement with plastic material, the concrete strength reached 28.88 MPa compared to the reference sample, which reached the strength of 29.11 MPa [13].

Foti 2013 [14] added to the concrete cut PET bottles, which were tested in three variants. The first variant was plastic rings 5 mm wide. The second variant was a plastic bottle cut in the longitudinal direction, with the two halves stacked on top of each other. The last variant was four overlapping layers of plastic. All three variants were added to the concrete with 1% vol. When evaluating the test results, a good interaction of the concrete with PET fibers was found, which absorbed the tensile stress [14].

Saikia and Brito, 2013 [15] added recycled PET aggregates in research, replacing natural aggregates with 5, 10 and 15% plastic aggregates. The added ingredients were in the form of coarsely chopped flakes, finely chopped flakes and plastic pellets. All three added forms of plastic had a positive effect on the hardened concrete when 10% was added. With the addition of 15%, the compressive strength has already decreased. In terms of absorbing properties, the concrete with the added plastic pellets with a ratio of 5% to 15% and concrete with fine flakes with a ratio of 5% to 10% showed the greatest match with the reference concrete. With the addition of 15%, the water absorption is noticeably increased. Most of the water was absorbed by the concrete with coarse flakes, which increased the water absorption with the increasing percentage of plastics in the concrete [15].

Rai et al., 2012 [16] in his research, he used plastic flakes as a fine aggregate to replace sand in a concrete mix. Replacement was tested with 0%, 5%, 10% and 15% plastic flakes. Furthermore, it tested the addition of fine plastic aggregates together with superlastifiers, thereby providing better workability at higher levels of plastic flakes. When 5%, 10% and 15% were added, the compressive strength decreased compared to the reference sample. The strength after 28 days was still approximately 40 MPa. As the percentage of plastic flakes increased, flexural strength was reduced. This reduction in strength is attributed to poor bonding of plastic particles and cement slurry [16].

Cordoba et al., 2013 [17] Conducted a research into the effect of particle size and size on the mechanical properties of concrete. He used recycled PET flakes of three different sizes for the test. Flake sizes were 0.5 mm, 1.5 mm and 3 mm. Three different concentrations of plastic flakes were tested for each size. These concentrations were 1%, 2.5% and 5% by volume of concrete. As expected, the particle size was found to affect the mechanical properties of the hardened concrete. Thus, smaller sizes of PET particles increase the modulus of elasticity. The highest compressive strength was achieved using 0.5 mm particles that were added to the concrete at 2.5% [17].

Raghatate, 2012 [18] added small pieces of plastic bags from 0% to 1% into a concrete matrix. The tests performed showed a reduction in compressive strength by adding 1% of plastic bags by approximately 20%. On the contrary, there was an increase in tensile strength using 0.8% plastic bags. Consequently, this material can be used for concretes in which tensile strength is required [18].

Fraternali et al., 2011 [19] tested the addition of recycled PET and non-recycled polypropylene. 1% of plastics was added to the concrete mix for both species. Experimental studies and comparative analysis have shown that recycled PET fibers could be a competitive technology in the future [19].
Al-Hashmi, 2010 [20] added granulated plastic waste to the concrete mix along with iron dust. Plastic waste added 5 and 10%. Iron dust added 0% - 50%. The results showed that these waste materials can be used in concrete mixtures. Using 5% granulated plastic, the compressed iron dust increased the compressive strength from about 48 MPa to about 53 MPa. Using 10% granulated plastic and adding iron dust up to 50%, the compressive strength rose from 48 MPa to about 54 MPa. The flexural strength was approximately 8 MPa [20].

Ochi et al., 2007, [21] in its publication deals with a method for the production of recycled PET fibers for concrete reinforcement. In order to ensure easy workability of the concrete mixture, the fibers were gradually added up to 3% [21].

N. Haghighatnejad et. al., 2016 [22] deals with the replacement of natural aggregate in concrete with PVC by recycled material in ratios of 20%, 30%, 40% and 50%. The concrete mixture is then tested by different types of curing since the curing process always has a direct effect on the final strength of the concrete. Based on the tests, it was found that the presence of recycled PVC reduces the drop of concrete in the cone test by up to 48%. In terms of strength, the largest reduction was observed in a sample with 50% PVC aggregate that was cured in a room with constant climate. This was about 39.4%. When comparing water curing and outdoor curing, strength decreased by about 23% in the outdoor environment. The best results were obtained with water curing for 14 and 7 days when the strength decreased by 7.3 and 9.8%. When comparing the results, it was found that concretes with the PVC aggregate are significantly more susceptible to lowering the air-curing strength than conventional concretes [22].

Mehmet Gesoglu et. al., 2017 [23] deals with the addition of 5%, 10%, 15%, 20%, and 25% plastic waste in the form of a concrete powder. Subsequently, after 28 days, the samples are tested for mechanical properties. On the basis of the tests, it was evaluated that the powder adversely affected the mechanical properties of the concrete, whereby the strength of the concrete decreased with increasing pressure, tension and bending strength as the proportion of plastic powder increased. The highest compressive strength drop was between 15% and 20% when the strength decreased by approximately 8 MPa. With the addition of 25% plastic powder, the strength decreased by about 15 MPa compared to the reference sample. A decrease was also observed in the tensile strength, which decreased by approximately 1.7 MPa. The flexural strength decreased by approximately 1 MPa [23].

S.C. Kou et. al. [24] they are investigating the addition of plastic to concrete instead of fine aggregate, which is obtained by crushing PVC pipes. The PVC aggregate is added to the concrete mixture at a ratio of 0%, 5%, 15%, 30% and 45%. Coarse aggregates are replaced by expanded clays (LWA) in the concrete mix. Based on the tests, the following conclusions were reached. The addition of PVC aggregate instead of fine aggregate reduced the processability of the concrete mixture. Furthermore, compressive strength and tensile strength were reduced. However, the formability of the concrete mixture was improved. Shrinkage and the ability to resist penetration of chloride ions have also been improved. In conclusion, crushed PVC pipes can be used in concrete mixtures. The ideal addition rate is 15% [24].

In his publication Y. Senhadji [25] deals with the replacement of fine and coarse aggregates with PVC aggregate. Natural river sand is replaced by PVC sand, the coarse natural aggregate is replaced by PVC aggregate of fraction 3/8. Replacement was 30%, 50%, and 70%. The results show that with increasing replacement ratio the workability of the concrete mixture was improved. Even at the addition of 30% the processability improved by 82%. When 70% was added, the specimens in the concrete cone fit test were up to 80 mm, an increase of 128% over the normal concrete mix. With such
an increase in workability, it is advisable to reduce the water coefficient to avoid great loss of strength. When testing the sample for strength, the tests showed a direct relationship between the added plastic and the compressive strength. This was always reduced by approximately 10 MPa with increasing proportions of added PVC particles. Despite this reduction, the concrete samples were qualified as the usable lightweight construction material of Concrete Class II. Mechanical properties could be improved by using high strength cements. Regarding the influence of PVC aggregate on the structure's resistance to chloride ions, here the results are good and PVC aggregate should be added to the concrete exposed to the aggressive environment [25].

H.H. Hussein et. al. [26] focused his publication on the acoustic and thermal properties of concrete with added PVC aggregate instead of sand. PVC waste was used from a plastic window and door factory. Sand replacement was performed with 2, 5%, 5%, 7.5%, 10%, 12.5% and 15%. The results have shown that concrete containing PVC aggregates has a lower thermal conductivity coefficient and increased sound absorption than normal concrete. In terms of strength, it meets the requirements for lightweight concrete [26].

S. Akcaozoglu et. al.,2012 [27]. He investigated the effect of added PET aggregates on the concrete mix for thermal conductivity of concrete, concrete strength and bulk density. Four samples with 30%, 40%, 50% and 60% PET aggregates were tested. The minimum thermal conductivity was measured for a sample of 60% PET aggregates, 0.3924 W / mK, which is 58% lower than the reference sample, but there was also a decrease in compressive strength to 11.1 MPa. The compressive strength of all samples decreased with increasing percentage of PET aggregate. Only the blend with 40% PET aggregate achieved the required strength and unit weight to be classified as lightweight [27].

Hakan Bolat and Pınar Erkus [28] focused their research on adding PVC waste combs to concrete and their impact on mechanical properties. PVC was added in the form of powder and granules at a ratio of 10%, 20% and 30%. Bulk density was 4% lower at 10%, 8% at 20% and 13% at 30%. The study also showed that it is possible to use such concrete when resistance to capillary water is required when water absorption has been reduced. This was observed in samples containing PVC powder. Furthermore, the abrasion resistance of the concrete structure using PVC granules was increased. However, when testing compressive strength, the strength with increasing proportions of PVC aggregates decreased [28].

T. Surekha, A. Chandrashekhar [29] tested mechanical properties when replacing cement with granulated blast furnace slag (GGBS) and silica along with polyvinyl chloride (PVC) dust. In all mixtures, cement was replaced in 8% silica. Furthermore, cement was replaced with 30% to 50% GGBS together with PVC dust 0% to 10%. The test results showed a higher compressive strength of GGBS without PVC dust compared to a reference mixture of approximately 9 MPa. Higher strength was measured until 40%. Cement was replaced with GGBS [29].

S. Akçaıızoğlu, C. Ulu [30] deals with the use of waste PET aggregates in alkali activated slag or metakaolin. Sodium hydroxide pellets (NaOH) and sodium silicate in the liquid state were used as activators. 20%, 40%, 60%, 80% and 100% PET aggregates were added to the mixtures. The results show satisfactory utilization of PET aggregates up to 80% in the production of lightweight concrete. The reference sample without the use of PET aggregate reached the strength of 70 MPa. After its addition, the PET aggregate achieved compressive strength of 58.6%, 49.9%, 32.3%, 24.6% and 18.6% of the original compressive strength of the reference sample. Bulk density, as well as tensile strength, also decreased with the increasing proportion of added PET aggregate. At the same time, water absorption increased [30].
Malek Batayneh et al. [31], in their study, they focused on the use of recycled glass, plastics and concrete in concrete. Fine aggregates have been replaced by up to 20% finely crushed plastic and glass. Coarse aggregates were replaced by up to 20% concrete recycled. The tests focused on the workability of concrete mixtures, their compressive strength, flexural strength and indirect tensile strength. The test results show that the addition of recycled glass has minimal effect on processability. Recycled plastic and concrete have already shown less concrete drop. The compressive strength of the recycled plastic was reduced. When using 20% plastics it was reduced to only 10 MPa from the original 34 MPa. The tensile strength and flexural strength were minimized. By contrast, using 20% recycled glass, the compressive strength increased by approximately 11 MPa. The tensile strength and flexural strength increased only a minimum of approximately 1 MPa. The last test sample with recycled concrete added had a decrease in compressive strength at 20% addition of about 4 MPa. The tensile strength and flexural strength decreased by approximately 1 MPa [31].

N. N. NIBUDEY et al., 2013 [32] focus on the use of waste plastics as fiber reinforcement in concrete. These fibers are 25 mm long and 1 mm and 2 mm wide. That is, with the aspect ratio of 35 and 50. Samples were made for both dimensions in which a fiber ratio of 0% to 3% was added. In the decrease test, both mixtures showed a smaller decrease in cone settling test compared to the reference mixture. A smaller decrease, however, was achieved by a mixture with a fiber ratio of 50 versus a ratio of 35. In terms of density, there was an increase in the addition of fibers at a ratio of 35 and a percentage of 0.5%. At more percent, the density decreased. The highest compressive strengths were found for samples with 35 and 50 fibers with 1% and 1.5% fibers respectively. Approximately 43 MPa. In measuring tensile strength and flexural strength, the best fiber results were a ratio of 50 when 1% was added to a concrete mixture, with a tensile strength of 4.1 MPa and a flexural strength of 6 MPa. Research has shown good concrete properties when adding plastic fibers of appropriate dimensions and proportions [32].

A.M. Azhdarpour, M. R et al. [33] investigate the effect of PET aggregate in the form of coarse and fine particles on the properties of concrete. PET aggregates were added to the concrete mixture at a rate of 0% - 30%. The best results were achieved by replacing 5% of the sand with PET aggregate, where the compressive strength increased by 39% and by 10% by 7.6%. Tensile and flexural strength have also increased. At higher percentages, the compressive strength was reduced. The modulus of elasticity decreased proportionally with an increasing percentage of PET aggregate in the concrete mixture. As the content of PET particles increased, the rate of sound propagation in concrete samples also decreased [33].

A study by Indradi Wijatmiko et al. [34] is engaged in the recycling of metal beverage cans that are cut into fibers and then used as reinforcement in concrete in a volume of 10%, 15% and 20%. The tested fibers were formed into three different shapes and subsequently, the effect of this shaping on the strength of the concrete was examined. The results show different concrete properties when adding different types in different proportions. The compressive strength of expanded concrete was increased by the addition of 15% of Type B fibers. Tensile strength has also been improved, which increased by 5-23% with the addition of type A fibers compared to normal concrete [34].

Alireza Mohammadinia et al., 2019 [35] published a study dealing with the use of recycled plastics and recycled glass in concrete. These materials are used as a substitute for natural aggregates. Aggregates were replaced by 10%, 20%, 30%, 40%, 50%. Compressive strength, tensile strength, and capillary water absorption were measured. The results showed satisfactory mechanical properties for concrete containing up to 20% recycled plastic waste and concrete containing up to 30% recycled glass. When replacing the aggregate with 10% plastic waste, it achieved the compressive strength of 38 MPa compared to a reference sample with a strength of 58 MPa. When replacing aggregate with 10% recycled glass, the compressive strength was 55 MPa. The reduced compressive strength results
from poor adhesion between the cement slurry and the recycled aggregates. The tensile strength was 3.1 MPa when replacing aggregate with 10% plastic waste. When replaced with 10% recycled glass, the tensile strength was 3.5 MPa. The reference sample had a tensile strength of 3.5 MPa. Water absorption increased when replacing aggregate with recycled plastic and glass. The study shows the usefulness of these recycled materials in, for example, pathways and pathways where up to 50% of recycled waste is replaced by natural aggregates [35].

3. Results and discussions
We can divide the tested samples according to the form of the added aggregate into dust particles with the size up to 1 mm, for flakes with the size of 1 - 10 mm, pellets with the size of 10 - 25 mm and fibers length 25 - 50 mm. According to the type of added plastic, the aggregates are divided into Polyvinyl chloride (PVC), Polyethylene terephthalate (PET), Polyethylene with high density (HDPE). When replacing the natural aggregate, the plastics were replaced by fine aggregates and coarse aggregates.

In general, concretes containing waste plastic aggregates in any form have less bulk density than conventional concretes and thus reduced compressive and tensile strength. For this reason, such concretes can be used as lightweight concretes for structures with lower strength requirements. A suitable aggregate is polyethylene terephthalate (PET) fibers. Some studies have shown an improvement in the mechanical properties of concrete using PET fibers with an aspect ratio of 50 at a volume of up to 5%. When larger PET aggregate particles are added, the workability of the concrete mixture is impaired and the water coefficient must be increased. Conversely, when the fines were added, the processability was improved and the water coefficient could be reduced. As a result, most samples exhibited lower compressive and tensile strengths. Some studies differ on the interaction of waste PET aggregate with cement filler. A study by Foti 2013 [14] describes a good interaction, but other studies suggest a reduction in compressive and tensile strength due to added PET aggregates, for example, a study by Rai et al., 2012 [16]. All studies show the improvement of the resistance of concrete structures after the addition of PET aggregates against aggressive environments and abrasion. Concrete containing PET aggregates showed better sulfuric acid resistance. Studies on the thermal and acoustic properties of concrete with the addition of PET aggregate show better results than the conventional concrete. PET aggregates reduce the thermal conductivity of concrete and better absorb sound. However, the strength of the concrete is reduced. Concrete containing PET aggregate in powder form shows good capillary water resistance.

4. Conclusions
After studying the studies, it turned out to be important to consider the form in which the plastic aggregate is used in the concrete mix. Different forms affect the different properties of the resulting concrete. Fibers can increase compressive and tensile strength when added in the correct percentage volume. Dust particles improve the resistance of the concrete structure to the aggressive environments and capillary water. Plastic flakes improve abrasion resistance. However, it is always necessary to determine the optimum ratio of plastic aggregate, natural aggregate, cement and water coefficient, otherwise, the interaction and loss of strength will deteriorate. For this reason, most of the tested samples met the conditions for use as the lightweight concrete. In the future, I see the potential for using waste plastics in concrete, either in terms of improving the mechanical properties or in terms of the environmental sustainability. However, prior to the actual use, it is necessary to determine the requirements for the future design and to select the appropriate plastic waste accordingly in an appropriate ratio and form, since all these factors will affect the mechanical properties of the resulting structure.
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