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GREEN CONCRETE PRODUCTION USING PARTIAL REPLACEMENT OF CRUSHED STONE FOR PET

PRODUÇÃO DE CONCRETO VERDE PELA SUBSTITUIÇÃO PARCIAL DE PÓ DE PEDRA POR PET

PRODUCCIÓN DE HORMIGÓN VERDE MEDIANTE EL REEMPLAZO PARCIAL DEL AGREGADO FINO POR EL PET

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Abstract: This scientific initiation paper proposes the performance evaluation of polyethylene terephthalate (PET) waste as a partial aggregate replacement of crushed stone in the green concrete production, to minimize the side effects of the construction industry. The mass substitution of the natural aggregate by PET crushed in the percentages of 10% and 15% by mass, achieved the density reduction and the criteria of minimum load bearing strength for structural purposes.
Keywords: Civil Construction. Crushed Stone. Green Concrete. PET.

Resumo: Este artigo de iniciação científica propõe a produção e a avaliação de desempenho de concretos verdes que possuem uma substituição parcial do agregado fino de pó de pedra por resíduos de tereftalato de polietileno (PET). A produção de concreto verde objetiva minimizar a quantidade de PET pós-consumo descartados em aterros, ou incinerados, pelo seu uso como material de consumo na indústria da construção civil. Os concretos verdes produzidos com substituição parcial de 10% e de 15% de agregado miúdo de pó de pedra por PET alcançaram a resistência à compressão e densidade que possibilita os seus usos para fins estruturais.
Palavras-chave: Concreto Verde. Construção Civil. PET. Pó de Pedra.

Resumen: Este artículo de iniciación científica propone la evaluación de la producción y el rendimiento de los hormigones verdes que tienen un reemplazo parcial del agregado fino de piedra arenisca con residuos de tereftalato de polietileno (PET). La producción de hormigón verde tiene como objetivo minimizar la cantidad de PET posconsumo desechado en vertederos, o incinerado, utilizándolo como material para el consumo en la industria de la construcción. Los concretos verdes producidos con reemplazo parcial de 10% y 15% de agregado fino por PET han alcanzado la resistencia a la compresión y la densidad que permite su uso para fines estructurales.
Palabras-clave: Hormigón Verde. Industria de la Construcción. PET. Piedra Arenisca.

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Introduction

The production of raw materials from extraction of minerals from the soil to the sustenance and evolution of our industrial society has modified the surface to the atmosphere of our planet and, to a certain extent, human survival itself (Barbera; Vymazal, 2019). The removal of minerals, in addition to altering the substrate, alters the various natural cycles directly and indirectly, either by the greater or lesser absorption of water by the exposed soil, or by the direct and indirect production of greenhouse gases during the removal of the minerals from the soil (Islam; Hye, 2018). Reported problems include troubles with greenhouse gases levels leading to an unbalanced fauna and flora cycles. These altered cycles are linked to the cycles of living beings and all of humanity, generating and increasing direct and indirect costs and, also, affecting human survival on the planet (Tuckett, 2019).

Green concrete is made with post-consumption materials (like industrial wastes) to reduce greenhouse gases (e.g., CO_2), following global or local emission regulamentations, on a large scale at minor environmental impact level, besides to reduce carbon footprint and decrease landfill spaces (Liew; Sojobi; Zhang, 2017). Thus, with the use of green concrete, it is possible to reduce CO_2 emissions and to reuse the post-consumption polymeric material (e.g., PET wastes) (Rahimi; Nikbin; Allahyari, 2016).

This work proposes the performance evaluation of polyethylene terephthalate (PET) waste as an aggregate replacement in the concrete manufacturing for green concrete, in order to minimize the side effects of the construction industry than the recovery of energy or landfilling (Foti, 2019).

To green concrete samples, crushed PET replaced the natural aggregate, stone powder, in percentages of 10%, 15% and 20% by mass. The compressive strength test performed after 28 days showed that the specimens were molded from the replaced mix showed significant improvement in comparison with specimens molded by the reference mix PET in percentages of 10% by mass meets the minimum strength of 20 MPa for structural concrete. The good performance for these green concretes is suitably standardized to ABNT NBR 9781: 2013, ABNT NBR 6118: 2014 and ASTM C936 / C936M: 2018.

Based on the above considerations the research is justified by the importance of green concrete to reduce greenhouse gases emissions and effects, besides in search of new methods and recyclable inputs to civil construction area, following international standards parameters.

Materials and Methods

For the study application, was used conventional materials in the concrete manufacturing using cement Portland V (ASTM C150 / C150M-18 and ASTM C150 / C150M-18), average sand, stone powder, coarse aggregate, water and high-performance superplasticizer additive (MC-Bauchemie, 2019). The high-performance superplasticizer was used to produce homogenous concrete without segregation and higher specifications for the finish (fair-faced concrete) thus, a concrete with high qualities (MC-PowerFlow 1080, 2019; Höfler; Schlumpf; Jahn, 2011).

Initially samples of the collect inputs were submitted to granulometry tests (Trent, 2014; ABNT NBR NM 248:2003). The concrete`s preparation was performed by using a free-fall concrete mixer, the PET was the last inputs to be added in the mixture. The manufacturing of cylindrical specimens molded in accordance with the proposals mixtures (cylindrical concrete samples) began after particle size distribution evaluated by sieving. Firstly, to produce concrete in test, a referential formulation mixture was chosen, that is, its standard reference trace (without PET aggregate). After reference trace definition, new dosages were admitted with the mass substitution of the natural aggregate, crushed stone, by PET crushed in the percentages of 10%, 15% and 20% by mass. PET fibers were made from the waste bottles and cut into the millimetric dimensions size to use in the concrete.

Setting the dosages, the casting of the pavers began, and 8 pieces were made in the dimensions 10mm×20mm×8mm using referential and PET experimental dosage (PET aggregates were produced from waste plastic). Before 24 hours, the pavers were unmolded and submitted to cure by water aspersion. After 28 days in water aspersion the concrete samples are fully cured provides and the samples were submitted to compression strength test. To obtain their physical properties several tests were performed according to ASTM C127 (ASTM C127-15).

Casting and Curing of concrete cylinder specimens were performed according to ASTM C192 (ASTM C143 / C143M-15a). Generally, the compressive strength of concrete differs

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according to the age (i.e. 14, 21 & 28 days), for this study 28 days of curing was considered as final cure for all samples. Slump test was performed according to ASTM C143/C143M and ASTM C39/C39M to compressive strength of cylindrical concrete specimens. The splitting tensile strength tests were performed according to ASTM C496 / C496M.

Results

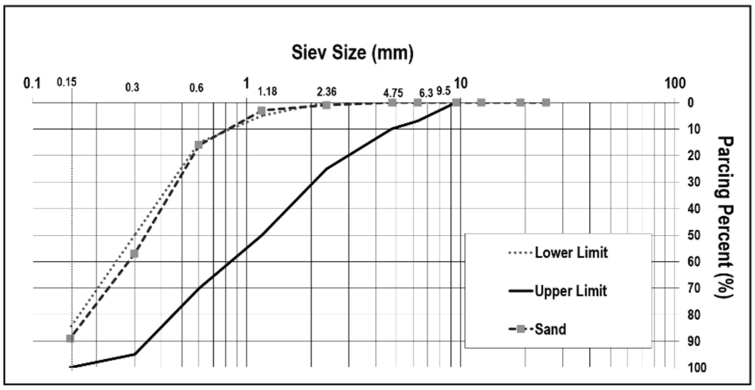
Cement

The Portland pozzolanic cement type III (CP-V, ARI) was used, according to ASTM C150 [18]. The CP V-ARI cement employed has a density of 3.1 g/cm³ and specific BET area of 1.0 m²/g.

Sand

Fine aggregate for concrete shall consist a natural screened and washed sand or crushed sand which having hard and durable particles, or of other inert materials with similar characteristics. The main fine aggregate used in this experiment was quartz sand. The size of the quartz sand for casting was modified according to ASTM C33 standard specification for concrete aggregates. The bulk density of sand is 1.55 g/cm³. According to granulometry's analysis performed, the small aggregate (sand) presents maximum dimension characteristic of 4.8 mm and fineness modulus equal to 2.97, as shown in Fig. 1.

Figure 1. Sieve analysis of fine aggregate.

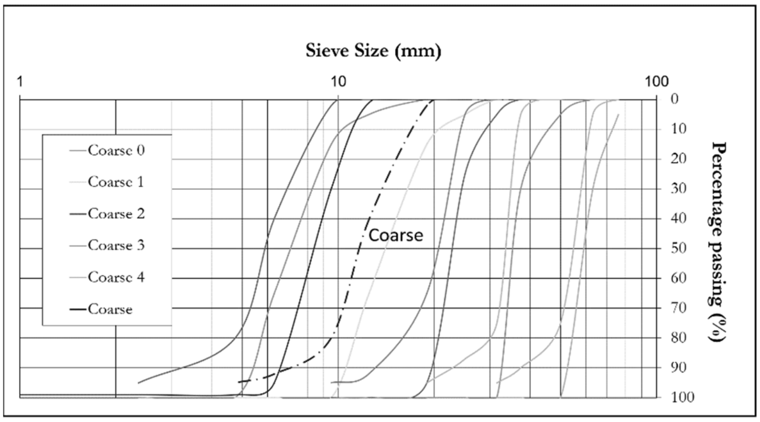


Source: Data from the authors.

Coarse aggregate

Coarse aggregate for concrete shall consist of natural gravel, crushed gravel, or crushed stone or other deleterious substances. The maximum characteristic size of gravel used in this research was 12.5 mm, as shown in Fig. 2. In addition, the aggregate has an absolute specific mass of 2.62 g/cm³ and an apparent specific mass of 1.48 g /cm³.

Figure 2. Sieve analysis of coarse aggregate.

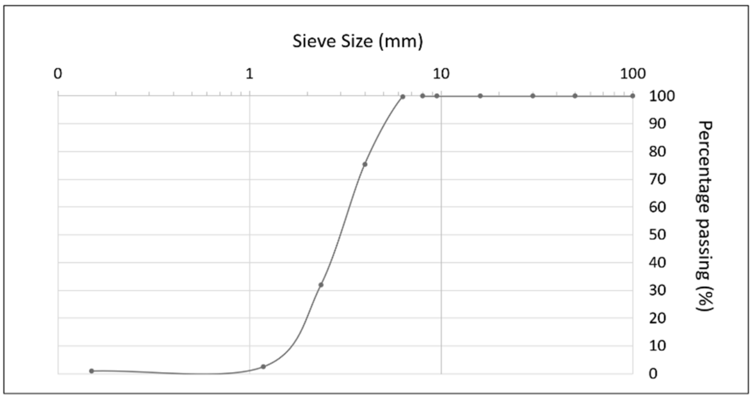


Source: Data from the authors.

PET

The maximum characteristic size of PET used in this research was 6.3 mm, as shown in Fig. 3. In addition, the aggregate has an absolute specific mass of 1.36 g/cm³ and an apparent specific mass of 0.28 g /cm³.

Figure 3. Sieve analysis of PET aggregate.



Source: Data from the authors.

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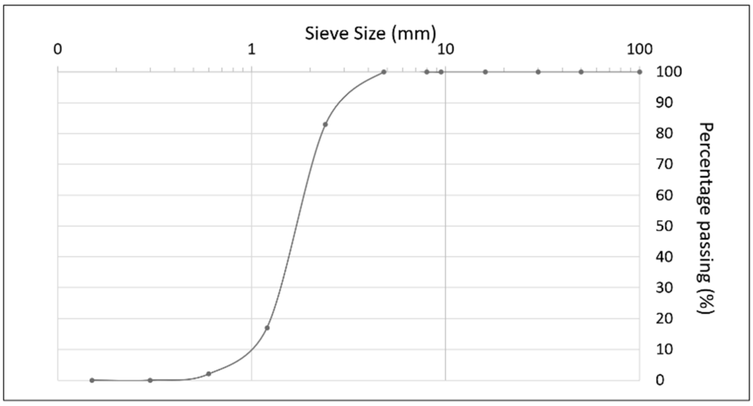
Crushed stone

The size of the crushed stone for casting was according to ASTM C33 standard specification for Class 1S particles to concrete aggregates. The bulk density of sand is 1.55 g/cm³. According to granulometry's analysis performed, the small aggregate presents maximum dimension characteristic of 4.8 mm and fineness modulus equal to 1.37, as shown in Fig. 4. In addition, the aggregate has an absolute specific mass of 2.64 g/cm³ and an apparent specific mass of 1.58 g/cm³.

Figure 4. Sieve analysis of Crushed Stone aggregate.



Source: Data from the authors.

Additive

Additives are chemicals products that are added to cement or concrete to modify one or more properties of cementitious mixtures (Ferreira et al., 2017). In this experiment was used MC PowerFlow 1080, a synthetic superplasticizer with specific mass of 1.09 g/cm³ on the MC-Polycarboxylate HER-technology (polycarboxylate polymer technology -PCE- developed by MC), to improve the initial concrete strength. The specific functioning mechanism makes it possible to produce concrete with low water contents, high- performance and no segregation. The traces in mass used to the concrete manufacturing were according MC recommendations of additive/cement of 0.2 to 5%.

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Preparation of concrete and molding of specimens

In order to study the behavior of the mechanical strength properties of reinforced concrete with PET, 10% (T 10%), 15% (T 15%) and 20% (T 20%) by mass of PET were added to the concrete mass, Table 1. By Table 1, the reference trace (TR) were produced with cement CP-V ARI, a coarse aggregate, water, quartz sand, crushed stone, and additive (MC Powerflow plasticizer). For the calculation of the concrete mix composition, the water cement ratio was 0.6, however, the addition of the plasticizer additive interferes in this ratio, then the new ratio became 0.5 for all mixtures. The mix design included Portland cement (c), sand fine aggregate (a), gravel coarse aggregate (b), and water/cement ratio (is this order) is presented below, respectively:

1: 2.75: 1.75:0:0.5

Table 1. Proposed composition of mix design

Concrete Mixer	Mix design (c: a: b:) kg	PET (kg)	Addition Crushed Stone (kg)	Additive (ml)	Age Test
TR	1: 2.75: 1.75	0.000	0.500	10.0	28 days
T 10%	1: 2.75: 1.75	0.050	0.450	10.0	28 days
T 15%	1: 2.75: 1.75	0.075	0.425	10.0	28 days
T 20%	1: 2.75: 1.75	0.100	0.400	10.0	28 days

Source: Data from the authors.

Table 1 shows the characteristics of the concrete mixer. As can be observed, the modification made were the PET and crushed stone aggregates. Subsequently, 48 cylindrical specimens were produced in the dimensions of 10 mm in diameter by 20 mm in height (ABNT NBR 5738:2015 and ASTM C192 / C192M-18).

Compressive strength

Figure 5 shows the mechanical properties evaluations of the reinforced concrete with PET were obtained through the compressive strength test (ABNT NBR 5739:2018). Analyzing the chart of Figure 5 it is possible to verify that the mass addition of PET after consumption

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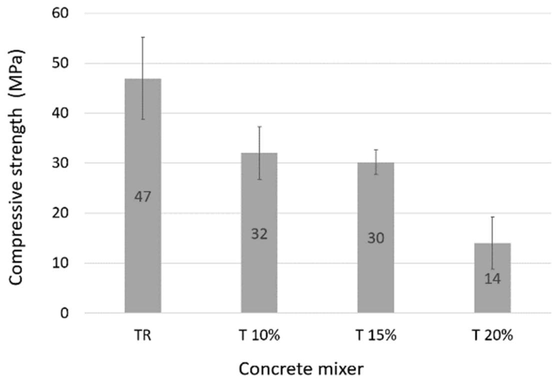
with the granulometry studied promotes a decrease in the compressive strength in all studied substitutions. At the age of 28 days the comparison between the reference specimens and the specimens replaced by 10% and by 15% by mass of PET provides a decrease of approximately 36% in compressive strength, whereas at 28 days, with the substitution of 20% the decrease is approximately 60%.

Figure 6. Data from the axial compressive strength test.



Source: Data from the authors.

The axial compression test consists of determining the maximum load of rupture supported by the specimen. For the accomplishment of this mechanical test, 3 test specimens of each type of concrete used in this study were tested. The compressive strength tests in Fig. 6 were carried out after 28 days of casting. From the observation of compressive strength vs. % PET/c ratio chart we found a decrease in compressive strength for partially PET and Crushed Stone added as concrete aggregates. The probable reason may be is, since the PET has smooth texture, it decreased strength for better bondage. The inter-face between the cement paste and aggregate known as ‘Transition zone’, which integrity influences the compressive strength of concrete, probably, not developed enough bondage between the aggregate and the cement paste.

In the results presented also, all the dosages with the mass substitution of the natural aggregate by PET crushed in the percentages of 10% and 15% by mass, achieved the minimum compressive strength of 20 MPa, recommended by for structural purposes (ABNT NBR 6118:2014). The results differ partially with the scientific literature (Krasna; Noor; Ramadani, 2019; Saikia; De Brito, 2014; Rahmani, 2013). This is probably due to MC- Polycarboxylate

HER-technology additive axial improved the concrete strength, being the compressive strength slightly higher that the literature PET concretes. Recent works by Needhidasan, Ramesh, and Prabu (2020) and Al-Hadithi, Noaman, and Mosleh (2019) also showed that the inclusion of PET fibers in concrete can also result in an increase in compressive and flexural strengths. The experimental study of Zanvettor et al. (2019) described that the PET wastes can replace aggregates and additionally has improved tensile strength in comparison with a polymer concrete without waste.

Water absorption test

The water absorption test (ASTM C642-13 and ASTM C1585-13) was done by immersion at atmospheric pressure. The density of the samples was measured after curing just before the compressive strength test to perform these tests, it was used three standard concrete specimens, as shown in Table 2. Table 2 shows the water absorption, apparent density, and apparent porosity results for the concrete specimens. Table 2 shows that specimens containing PET and Crushed Stone showed greater water absorption when compared to reference trace specimens (TR) probably due to its lower density and mainly greater porosity. It was found that a gradual reduction in density of PET concrete compared to TR. But T 10% lower density than PET and Crushed Stone concretes. It has also been observed that the porosity of the concrete increases with the increase of PET as Crushed Stone.

Table 2. Water Absorption test

Concrete mixer	Water Absorption (%)	Apparent Density (kg/m³)	Apparent Porosity (%)
TR	3.0	1630	4.5
T 10%	3.5	1530	5.4
T 15%	4.0	1560	5.2
T 20%	5.0	1550	8.0

Source: Data from the authors.

Workability

The slump, in the workability test (ASTM C143 / C143M-15a), generally increases proportionally with the water content of a given concrete mixture, and thus to be inversely

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related to concrete strength, but from the test results, it was observed that for same w/c ratio, slump value was lower for PET concrete which indicated lower workability for PET concrete compared to TR. The smooth texture of PET gives it less surface area but more voids than the brick aggregates.

Cost

The estimate cost of molding of specimens in case of PET crushed in the percentages of 10% and 15% by mass is around 0.004-0.007 US dollar (USD) per kg more economical than TR. Weight of a molding of specimens was practically the same weight (around 0.020% per kg less than TR). Even replacing all virgin aggregates with recycled aggregates will reduce CO_2 emissions by only 1%. But the use of recycled aggregates is important as it can reduce landfills and support sustainable development (Kassa; Kanali; Ambassah, 2019). So, there is a need to incentivize its use (Obla, 2009).

Conclusions

The present experimental paper deals with the possibility of using PET post consumption aggregate to obtain a concrete mixture with the purpose of identifying a better approach for waste plastic recycling. Several experiments have been performed and results have been analyzed to justify the possibility. The experimental results lead to the following conclusions:

- The PET can be used as an alternative for coarse aggregates in concrete preparation. Along with the density reduction it also satisfies the criteria of minimum load bearing strength for structural purposes.
- Due to the shape and smooth surface structure of the PET the workability of concrete has been reduced which should be improved by adding water reducing admixture.

Therefore, the addition of post-consumption crushed PET to the concrete intended for green concretes is very promising at a dosage until 10% by mass, at the same time provides lower costs of production and PET post-consumption residue in the environment, consequently, a CO_2 emission reduction.

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